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Thomas L. Saaty
Luis G. Vargas

Models, Methods, Concepts & Applications of the Analytic Hierarchy Process

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Thomas L. Saaty
Katz Graduate School of Business and College of Business Administration
University of Pittsburgh
Mervis Hall, Pittsburgh
PA 15260
USA

Luis G. Vargas
Katz Graduate School of Business and College of Business Administration
University of Pittsburgh
Mervis Hall, Pittsburgh
PA 15260
USA

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Preface

This book is a collection of selected applications of the Analytic Hierarchy Process (AHP) in economic, social, political and technological areas. This volume along with other volumes on decision making, planning, conflict resolution and forecasting, rounds out the diversity of application areas of the AHP.

We have been particularly interested in three themes: economics, the social sciences and the linking of measurement with human values. The AHP offers economists a substantially different approach to deal with economic problems through ratio scales. The main mathematical models on which economics has based its quantitative thinking up to now are utility theory which uses interval scales and linear programming. The axiomatic foundation of utility theory uses gambles or lotteries to elicit judgments about utilities from decision makers. Over the years, practitioners of utility theory have encountered paradoxes that contradict the basic axioms of their theory. Some of the developers of the paradoxes have even won Nobel prizes for their findings. We hope that the variety of examples included here can perhaps stimulate some readers to try applying this new approach.

The second theme is concerned with the social sciences. The AHP offers psychologists, sociologists and political scientists the methodology they have sought for some time to quantify and derive measurements for intangibles. We hope that the examples included in this book will induce them to study the theory. It should quickly become clear that the AHP is the kind of instrument they have been seeking.

The third theme is concerned with providing people in the physical and engineering sciences with a quantitative method to link hard measurement to human values. In such a process one needs to interpret what the measurements mean. A number is useless until someone understands what it means. It can have different meanings in different problems. Ten dollars are plenty to satisfy ones hunger but are useless by themselves in buying a new car. Such measurements are only indicators of the state of a system, but do not relate to the values of the human observers of that system.

Many of the applications in this book were sponsored, co-authored or supervised by the first author in his classes and in his research, and some by the second author. Our friendship has often brought us together to carry out a project that would otherwise be onerous for one person to do. We enjoy thinking of the topics, motivating the works and performing the task of collecting and bringing together what appears to us of potential interest to readers and users of the Analytic Hierarchy Process. Most of these studies have been edited and shortened but their essence preserved. We believe that the AHP is a general tool that is helpful in assisting the mind to organize its thoughts and experiences and to elicit judgments recorded in memory.

The first author has already put together another volume on applications with feedback and dependence using the network version of the AHP known as the Analytic Network Process (ANP). That topic is also studied by the first author in a chapter of his book "Fundamentals of Decision Making in Priority Theory with the Analytic Hierarchy Process" published in 1994 as the sixth volume of the AHP series and in a new book entitled "The Analytic Network Process" first published in 1996 and revised in 2001.

We would like to thank and acknowledge the contributions of the following individuals without whom this volume would not have been possible: Miguel Beltran (Chap. 3), Arthur P. Dobias (Chap. 5), Graydon L. Karlson (Chap. 6), Thomas Palamides, Dermot Gray and Dennis DiPalma (Chap. 7), Vasudevan Ramanujam (Chap. 9), Gianfranco Tripido and Natalino Dazzi (Chap.10), Yoram Wind (Chap. 11), Katheleen A. Broker, Carol A. Calloway, Alberto L. Casadei, Jeffrey M. Jacobs, Vincent J. Kruse and Matthew W. Miller (Chap. 12), Andrew Blair and Robert Nachtmann (Chap. 13), H. J. Zoffer (Chap. 15), Charmienne M. Ganao and Betsy Monroe (Chap. 16), Michael Gillespie and Stephen E. Katch (Chap. 17), Dan Caste and Michael Saghy (Chap. 18), Delena Spencer and Marie Reed (Chap. 19), Wendy Ann Clayton, Melissa Wright and Wendy Snodgrass Sarver (Chap. 20), Hameed G. Nezad and Alan Baharlou (Chap. 21), J. W. France and Kathy R. Valentine (Chap. 22), Sudha Iyengar and Vijaya Ghandi (Chap. 23), and Thomas A. Kasperski, John J. Umphred and Andrew F. Firlik (Chap. 24).

Some of the chapters in this volume were reports prepared for graduate courses taught by the first author (Chaps. 3, 5–7, 9 , 10, 16–21, 23 and 24) and by the second author (Chap. 12). We are grateful to these authors for permission to include their edited materials in the book. The excellent collection of articles included here has been made possible because of their contributions.

Contents

Chapter 1
How to Make a Decision

1.1 Introduction

ἱερά ἀρχή is the Greek word for hierarchy meaning holy origin or holy rule.[1] It is the ordering of parts or elements of a whole from the highest to the lowest. A hierarchy is the principle of control that secures the effective functioning of the organization.[2]

"You can't compare apples and oranges," so the saying goes. But is this true? Consider a hungry person who likes both apples and oranges and is offered a choice between a large, red, pungent, juicy looking Washington State apple and an even larger, old and shriveled, pale colored orange with a soft spot. Which one is that person more likely to choose? Let us reverse the situation and offer the same person on the next day a small, deformed, unripe apple with a couple of worm holes and a fresh colored navel orange from California. Which one is he or she more likely to choose now?

We have learned through experience to identify properties and establish selection criteria for apples and oranges and in fact we use that experience to make tradeoffs among the properties and reach a decision. We choose the apple or orange that yields, according to our preferences, the greater value across all the various attributes.

The Analytic Hierarchy Process (AHP) is a basic approach to decision making. It is designed to cope with both the rational and the intuitive to select the best from a number of alternatives evaluated with respect to several criteria. In this process, the decision maker carries out simple pairwise comparison judgments which are then used to develop overall priorities for ranking the alternatives. The AHP both allows for inconsistency in the judgments and provides a means to improve consistency.

[1] Encyclopedia Catholica.
[2] The Great Soviet Encyclopedia, Moscow 1970.

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The simplest form used to structure a decision problem is a hierarchy consisting of three levels: the goal of the decision at the top level, followed by a second level consisting of the criteria by which the alternatives, located in the third level, will be evaluated. Hierarchical decomposition of complex systems appears to be a basic device used by the human mind to cope with diversity. One organizes the factors affecting the decision in gradual steps from the general, in the upper levels of the hierarchy, to the particular, in the lower levels. The purpose of the structure is to make it possible to judge the importance of the elements in a given level with respect to some or all of the elements in the adjacent level above. Once the structuring is completed, the AHP is surprisingly simple to apply.

In this chapter we show that there is a real and practical use for judgments and priorities in human affairs. This use is not contrived; we are led to them in a very natural way.

1.2 How to Structure a Decision Problem

Perhaps the most creative task in making a decision is deciding what factors to include in the hierarchic structure. When constructing hierarchies one must include enough relevant detail to represent the problem as thoroughly as possible, but not so thoroughly as to lose sensitivity to change in the elements. Considering the environment surrounding the problem, identifying the issues or attributes that one feels should contribute to the solution, and who are the participants associated with the problem, are all important issues when constructing a hierarchy. Arranging the goals, attributes, issues, and stakeholders in a hierarchy serves two purposes: It provides an overall view of the complex relationships inherent in the situation and in the judgment process, and it also allows the decision maker to assess whether he or she is comparing issues of the same order of magnitude.

The elements being compared should be homogeneous. The hierarchy does not need to be complete; that is, an element in a given level does not have to function as a criterion for *all* the elements in the level below. Thus a hierarchy can be divided into subhierarchies sharing only a common topmost element. Further, a decision maker can insert or eliminate levels and elements as necessary to clarify the task of setting priorities or to sharpen the focus on one or more parts of the system. Elements that are of less immediate interest can be represented in general terms at the higher level of the hierarchy and elements of critical importance to the problem at hand can be developed in greater depth and specificity. The task of setting priorities requires that the criteria, the subcriteria, the properties or features of the alternatives be compared among themselves in relation to the elements of the next higher level.

Finally, after judgments have been made on the impact of all the elements, and priorities have been computed for the hierarchy as a whole, sometimes, and with care, the less important elements can be dropped from further consideration because of their relatively small impact on the overall objective.

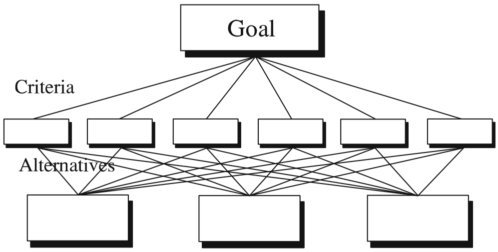


Fig. 1.1 A three level hierarchy

1.3 Philosophy, Procedure and Practice of the AHP

The Analytic Hierarchy Process is a general theory of measurement. It is used to derive ratio scales from both discrete and continuous paired comparisons in multilevel hierarchic structures. These comparisons may be taken from actual measurements or from a fundamental scale that reflects the relative strength of preferences and feelings. The AHP has a special concern with departure from consistency and the measurement of this departure, and with dependence within and between the groups of elements of its structure. It has found its widest applications in multicriteria decision making, in planning and resource allocation, and in conflict resolution [6, 8]. In its general form, the AHP is a nonlinear framework for carrying out both deductive and inductive thinking without use of the syllogism. This is made possible by taking several factors into consideration simultaneously, allowing for dependence and for feedback, and making numerical tradeoffs to arrive at a synthesis or conclusion (see Figs. 1.1 , 1.2).

For a long time people have been concerned with the measurement of both physical and psychological events. By physical we mean the realm of what is fashionably known as the tangibles in so far as they constitute some kind of objective reality outside the individual conducting the measurement. By contrast, the psychological is the realm of the intangibles, comprising the subjective ideas, feelings, and beliefs of the individual and of society as a whole. The question is whether there is a coherent theory that can deal with both these worlds of reality without compromising either. The AHP is a method that can be used to establish measures in both the physical and social domains.

In using the AHP to model a problem, one needs a hierarchic or a network structure to represent that problem, as well as pairwise comparisons to establish relations within the structure. In the discrete case these comparisons lead to dominance matrices and in the continuous case to kernels of Fredholm Operators [12], from which ratio scales are derived in the form of principal eigenvectors, or eigenfunctions, as the case may be. These matrices, or kernels, are positive and reciprocal, e.g., $a_{ij} = 1/a_{ji}$. In particular, special effort has been made to characterize these matrices [6, 16]. Because of the need for a variety of judgments, there has also been considerable work done to deal with the process of synthesizing group judgments [7].

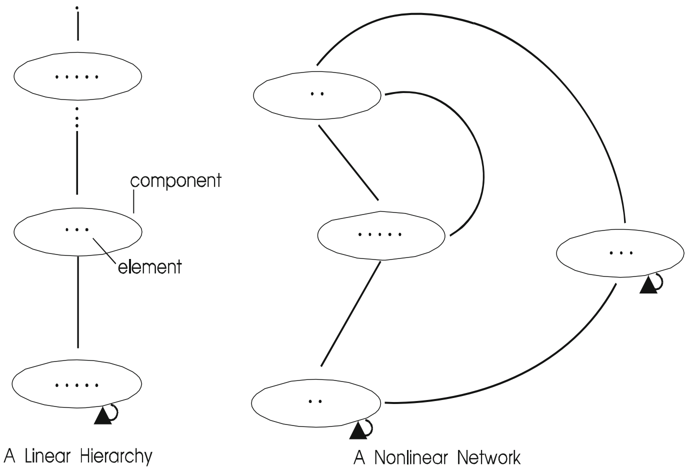


Fig. 1.2 Structural difference between a linear and a non linear network

For completeness we mention that there are four axioms in the AHP. Briefly and informally they are concerned with the reciprocal relation, comparison of homogeneous elements, hierarchic and systems dependence and with expectations about the validity of the rank and value of the outcome and their dependence on the structure and its extension [7].

1.4 Absolute and Relative Measurement and Structural Information

Cognitive psychologists have recognized for some time that there are two kinds of comparisons that humans make: absolute and relative. In absolute comparisons, alternatives are compared with a standard or baseline which exists in one's memory and has been developed through experience. In relative comparisons, alternatives are compared in pairs according to a common attribute. The AHP has been used with both types of comparisons to derive ratio scales of measurement. We call such scales absolute and relative measurement scales. Relative measurement w_i, $i = 1,\ldots, n$, of each of n elements is a ratio scale of values assigned to that element and derived by comparing it in pairs with the others. In paired comparisons two elements i and j are compared with respect to a property they have in common. The smaller i is used as the unit and the larger j is estimated as a multiple of that unit in the form $(w_i/w_j)/1$ where the ratio w_i/w_j is taken from a fundamental scale of absolute values.

Absolute measurement (sometimes called scoring) is applied to rank the alternatives in terms of either the criteria or the ratings (or intensities) of the criteria; for example: excellent, very good, good, average, below average, poor, and very poor; or A, B, C, D, E, F, and G. After setting priorities for the criteria (or subcriteria, if there are any), pairwise comparisons are also made between the ratings themselves to set priorities for them under each criterion and dividing each of their priorities by the largest rated intensity to get the ideal intensity. Finally, alternatives are scored by checking off their respective ratings under each criterion and summing these ratings for all the criteria. This produces a ratio scale score for the alternative. The scores thus obtained of the alternatives can in the end be normalized by dividing each one by their sum.

Absolute measurement has been used in a variety of applications. For example, it has been used to rank cities in the United States according to nine criteria as judged by six different people [13]. Another appropriate use for absolute measurement is in school admissions as in Chap. 22 [14]. Most schools set their criteria for admission independently of the performance of the current crop of students seeking admission. The school's priorities are then used to determine whether a given student meets the standard set for qualification. Generally, candidates are compared with previously set standard rather than with each other. In that case absolute measurement should be used to determine which students meet prior standards and qualify for admission.

1.5 The Fundamental Scale

Paired comparison judgments in the AHP are applied to pairs of homogeneous elements. The fundamental scale of values to represent the intensities of judgments is shown in Table 1.1. This scale has been validated for effectiveness, not only in many applications by a number of people, but also through theoretical justification of what scale one must use in the comparison of homogeneous elements.

There are many situations where elements are equal or almost equal in measurement and the comparison must be made not to determine how many times one is larger than the other, but what fraction it is larger than the other. In other words there are comparisons to be made between 1 and 2, and what we want is to estimate verbally the values such as 1.1, 1.2,…, 1.9. There is no problem in making the comparisons by directly estimating the numbers. Our proposal is to continue the verbal scale to make these distinctions so that 1.1 is a "tad", 1.3 indicates moderately more, 1.5 strongly more, 1.7 very strongly more and 1.9 extremely more. This type of refinement can be used in any of the intervals from 1 to 9 and for further refinements if one needs them, for example, between 1.1 and 1.2 and so on.

Table 1.1 The fundamental scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

The following two examples provide partial validation of the 1–9 scale used in the pairwise comparisons of homogeneous elements.

Which drink is consumed more in the US?

	A	B	C	D	E	F	G	Estimated	Actual
A:Coffee	1	9	5	2	1	1	1/2	0.177	0.18
B:Wine	1/9	1	1/3	1/9	1/9	1/9	1/9	0.019	0.01
C:Tea	1/5	3	1	1/3	1/4	1/3	1/9	0.042	0.04
D:Beer	1/2	9	3	1	1/2	1	1/3	0.116	0.12
E:Sodas	1	9	4	2	1	2	1/2	0.190	0.18
F:Milk	1	9	3	1	1/2	1	1/3	0.129	0.14
G:Water	2	9	9	3	2	3	1	0.327	0.33

C.R. = 0.022

Which food has more protein?

	A	B	C	D	E	F	G	Estimated	Actual
A:Steak	1	9	9	6	4	5	1	0.345	0.37
B:Potatoes	1/9	1	1	1/2	1/4	1/3	1/4	0.031	0.04
C:Apples	1/9	1	1	1/3	1/3	1/5	1/9	0.030	0.00
C:Soybeans	1/6	2	3	1	1/2	1	1/6	0.065	0.07
E:Whole wheat bread	1/4	4	3	2	1	3	1/3	0.124	0.11
F:Tasty cake	1/5	3	5	1	1/3	1	1/5	0.078	0.09
G:Fish	1	4	9	6	3	5	1	0.328	0.32

C.R. = 0.028

1.6 Comments on Benefit/Cost Analysis

Often, the alternatives from which a choice must be made in a choice-making situation have both costs and benefits associated with them. In this case it is useful to construct separate costs and benefits hierarchies, with the same alternatives on the bottom level of each. Thus one obtains both a costs-priority vector and a benefit-priority vector. The benefit/cost vector is obtained by taking the ratio of the benefit priority to the costs priority for each alternative, with the highest such ratio indicating the preferred alternative. In the case where resources are allocated to several projects, such benefit-to-cost ratios or the corresponding marginal ratios prove to be very valuable.

For example, in evaluating three types of copying machines, the good attributes are represented in the benefits hierarchy and the costs hierarchy represents the pain and economic costs that one would incur by buying or maintaining each of the three types of machines. Note that the criteria for benefits and the criteria for costs need not be simply opposites of each other but instead may be partially or totally different. Also note that each criterion may be regarded at a different threshold of intensity and that such thresholds may themselves be prioritized according to desirability, with each alternative evaluated only in terms of its highest priority threshold level. Similarly, three hierarchies can be used to assess a benefit/(cost $\times$ risk) outcome.

1.7 The Eigenvector Solution for Weights and Consistency

There is an infinite number of ways to derive the vector of priorities from the matrix (a_{ij}). But emphasis on consistency leads to the eigenvalue formulation $Aw = nw$. To see this, assume that the priorities $w = (w_1,\ldots,w_n)$ with respect to a single criterion are known, such as the weights of stones, we can examine what we have to do to recover them. So we form the matrix of ratio comparisons and multiply it on the right by w to obtain nw as follows:

$$\begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{pmatrix} \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix} = n \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix}$$

If a_{ij} represents the importance of alternative i over alternative j and a_{jk} represents the importance of alternative j over alternative k and a_{ik}, the importance of alternative i over alternative k, must equal $a_{ij}a_{jk}$ or $a_{ij}a_{jk} = a_{ik}$ for the judgments to be consistent. If we do not have a scale at all, or do not have it conveniently as in the case of some measuring devices, we cannot give the precise values of w_i / w_j but only an estimate. Our problem becomes $A'\ w' = \lambda_{\max} w'$ where $\lambda_{\max}$ is the largest or principal eigenvalue of $A' = (a'_{ij})$ the perturbed value of $A = (a_{ij})$ with the reciprocal $a'_{ji} = 1 / a'_{ij}$ forced. To simplify the notation we shall continue to write $Aw = \lambda_{\max} w$ where A is the matrix of pairwise comparisons.

The solution is obtained by raising the matrix to a sufficiently large power, then summing over the rows and normalizing to obtain the priority vector $w = (w_1, \ldots, w_n)$. The process is stopped when the difference between components of the priority vector obtained at the kth power and at the (k+1)st power is less than some predetermined small value. The vector of priorities is the derived scale associated with the matrix of comparisons. We assign in this scale the value zero to an element that is not comparable with the elements considered.

An easy way to get an approximation to the priorities is to normalize the geometric means of the rows. This result coincides with the eigenvector for $n \leq 3$. A second way to obtain an approximation is by normalizing the elements in each column of the judgment matrix and then averaging over each row.

We would like to caution that for important applications one should use only the eigenvector derivation procedure because approximations can lead to rank reversal in spite of the closeness of the result to the eigenvector [10].

A simple way to obtain the exact value (or an estimate) of $\lambda_{\max}$ when the exact value (or an estimate) of w is available in normalized form is to add the columns of A and multiply the resulting vector by the priority vector w.

The problem now becomes, how good is the principal eigenvector estimate w? Note that if we obtain $w = (w_1, \ldots, w_n)^T$, by solving this problem, the matrix whose entries are w_i/w_j is a consistent matrix which is our consistent estimate of the matrix A. The original matrix itself A, need not be consistent. In fact, the entries of A need not even be transitive; i.e., A_1 may be preferred to A_2 and A_2 to A_3 but A_3 may be preferred to A_1. What we would like is a measure of the error due to inconsistency. It turns out that A is consistent if and only if $\lambda_{\max} = n$ and that we always have $\lambda_{\max} \geq n$.

It is interesting to note that $(\lambda_{\max} - n)/(n - 1)$ is the variance of the error incurred in estimating a_{ij}. This can be shown by writing $a_{ij} = (w_i / w_j)\varepsilon_{ij}$, $\varepsilon_{ij} > 0$,

Table 1.2 Average random consistency index (R.I.)

N	1	2	3	4	5	6	7	8	9	10
Random consistency index (R.I.)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

$\varepsilon_{ij} = 1 + \delta_{ij}$, $\delta_{ij} > -1$, and substituting in the expression for λ_{max}. It is δ_{ij} that concerns us as the error component and its value $|\delta_{ij}| < 1$ for an unbiased estimator. The measure of inconsistency can be used to successively improve the consistency of judgments. The consistency index of a matrix of comparisons is given by C.I. $= (\lambda_{max} - n)/(n - 1)$. The consistency ratio (C.R.) is obtained by comparing the C.I. with the appropriate one of the following set of numbers (See Table 1.2) each of which is an average random consistency index derived from a sample of randomly generated reciprocal matrices using the scale 1/9, 1/8,..., 1,..., 8, 9. If it is not less than 0.10, study the problem and revise the judgments. The AHP includes a consistency index for an entire hierarchy. An inconsistency of 10 percent or less implies that the adjustment is small compared to the actual values of the eigenvector entries. A proof that the number of elements should be small to preserve consistency can be found in [6].

1.8 How to Structure a Hierarchy

Perhaps the most creative and influential part of decision making is the structuring of the decision as a hierarchy. The basic principle to follow in creating this structure is always to see if one can answer the following question: "Can I compare the elements on a lower level in terms of some or all of the elements on the next higher level?"

A useful way to proceed is to work down from the goal as far as one can and then work up from the alternatives until the levels of the two processes are linked in such a way as to make comparison possible. Here are some suggestions for an elaborate design.

1. Identify overall goal. What are you trying to accomplish? What is the main question?
2. Identify subgoals of overall goal. If relevant, identify time horizons that affect the decision.
3. Identify criteria that must be satisfied in order to fulfill the subgoals of the overall goal.
4. Identify subcriteria under each criterion. Note that criteria or subcriteria may be specified in terms of ranges of values of parameters or in terms of verbal intensities such as high, medium, low.
5. Identify actors involved.
6. Identify actor goals.
7. Identify actor policies.

8. Identify options or outcomes.
9. Take the most preferred outcome and compare the ratio of benefits to costs of making the decision with those of not making it. Do the same when there are several alternatives from which to choose.
10. Do benefit/cost analysis using marginal values. Because we are dealing with dominance hierarchies, ask which alternative yields the greatest benefit; for costs, which alternative costs the most.

The software program Expert Choice [2] incorporates the AHP methodology and enables the analyst to structure the hierarchy and resolve the problem using relative or absolute measurements, as appropriate.

1.9 Hierarchic Synthesis and Rank

Hierarchic synthesis is obtained by a process of weighting and adding down the hierarchy leading to a multilinear form. The hierarchic composition principle is a theorem in the AHP that is a particular case of network composition which deals with the cycles and loops of a network.

What happens to the synthesized ranks of alternatives when new ones are added or old ones deleted? The ranks cannot change under any single criterion, but they can under several criteria depending on whether one wants the ranks to remain the same or allow them to change. Many examples are given in the literature showing that preference reversal and rank reversal are natural occurrences. In 1990 Tversky et al. [18] concluded that the "primary cause" of preference reversal is the "failure of procedure invariance". In the AHP there is no such methodological constraint.

In the distributive mode of the AHP, the principal eigenvector is normalized to yield a unique estimate of a ratio scale underlying the judgments. This mode allows rank to change and is useful when there is dependence on the number of alternatives present or on dominant new alternatives which may affect preference among old alternatives thus causing rank reversals (see phantom alternatives [7]). In the ideal mode of the AHP the normalized values of the alternatives for each criterion are divided by the value of the highest rated alternative. In this manner a newly added alternative that is dominated everywhere cannot cause reversal in the ranks of the existing alternatives [6].

1.10 Normative: Descriptive

All science is descriptive not normative. It is based on the notion that knowledge is incomplete. It uses language and mathematics to understand, describe and predict events with the object of testing the accuracy of the theory. Events involve two things: (1) controllable and uncontrollable conditions (e.g. laws) and (2) people or objects characterized by matter, energy and motion influenced by and sometimes influencing these conditions. A missile's path is subject to uncontrollable forces like gravity and controllable forces like the initial aim of the missile, its weight, perhaps the wind, and others. The conditions are not determined by the objects involved. The idea is to get the missile from A to B by ensuring that it follows its path with precision.

Economics is normative. It is based on expected utility theory and is predicated on the idea that the collective behavior of many individuals, each motivated by self interest, determines the market conditions which in turn influence or control each individual's behavior. In this case both the objects and the conditions are "up for grabs" because behavior is subject to rational influences that are thought to be understood. By optimizing individual behavior through rationality one can optimize the collective conditions and the resulting system, plus or minus some corrections in the conditions. But conditions are not all economic. Some are environmental, some social, some political and others cultural. We know little about their interactions. In attempting to include everything, normative theories treat intangible criteria as tangibles by postulating a convenient economic scale. It is hard to justify reducing all intangibles to economics in order to give the appearance of completeness. It is doubtful that economic theory can solve all human problems. To the contrary, some believe that it can create problems in other areas of human concern.

A normative theory is established by particular people external to the process of decision making. Experts often disagree on the criteria used to judge the excellence of a normative theory and the decision resulting from it. For example, a basic criterion of Utility Theory is the principle of rationality which says that if a person is offered more of that which he values, he should take it. In response to this dictum Herbert Simon [17] developed his idea of sufficiency (satisficing). Whenever we are saturated even with a highly valued commodity, there is a cutoff point where the marginal increase in total value is less than or equal to zero. A theory constructed to satisfy such an assumption would undoubtedly encounter difficulties in its applications. Rank reversals would be appropriate to overcome the disadvantages of oversaturation.

The AHP is a descriptive theory in the sense of the physical sciences. It treats people separately from the conditions in which they find themselves, because so far no complete integrated theory of socio-economic-political-environmental-cultural factors exists that would enable us to deduce optimality principles for people's behavior. The AHP is an instrument used to construct a complete order through which optimum choice is derived.

In the AHP approach a particular decision is not considered wrong merely because it does not follow a prescribed set of procedures. The purpose of the AHP is to assist people in organizing their thoughts and judgments to make more effective decisions. Its structures are based on observations of how influences are transmitted and its arithmetic is derived from psychologists' observations of how people function in attempting to understand their behavior.

In its simplest form, the AHP begins with the traditional concept of ordinal ranking to stratify a hierarchy and advances further into numerical paired comparisons from which a ranking of the elements in each level is derived. By imposing a multiplicative structure on the numbers ($a_{ij} \cdot a_{jk} = a_{ik}$), the reciprocal condition is obtained. Thus, the AHP infers behavioral characteristics of judgments (inconsistency and intransitivity) from its basic framework of paired comparisons. It begins by taking situations with a known underlying ratio scale and hence known comparison ratios, and shows how its method of deriving a scale uniquely through the eigenvector gives back the original scale. Then, through perturbation the AHP shows that a derived scale should continue (through the eigenvector) to approximate the original scale providing that there is high consistency.

1.11 Rationality

Rationality is defined in the AHP as:

- Focussing on the goal of solving the problem;
- Knowing enough about a problem to develop a thorough structure of relations and influences;
- Having enough knowledge and experience and access to knowledge and experience of others to assess the priority of influence and dominance (importance, preference or likelihood to the goal as appropriate) among the relations in the structure;
- Allowing for differences in opinion with an ability to develop a best compromise.

1.12 Examples

Relative Measurement: Choosing the Best House

To illustrate the ideas discussed above regarding relative measurement, consider the following example; a family of average income wants to purchase a house. They must choose from three alternatives. The family identifies eight factors to look for in a house. These factors fall into three categories: economic, geographic, and physical. Although one might begin by examining the relative importance of these categories, the family feels they want to prioritize the relative importance of all the factors without working with the categories to which they belong. The problem is to select one of three candidate houses. In applying the AHP, the first step is *decomposition*, or the structuring of the problem into a hierarchy (see Fig. 1.3). On the first (or top) level is the overall goal of *Satisfaction with House*. On the second level are the eight factors or criteria that contribute to

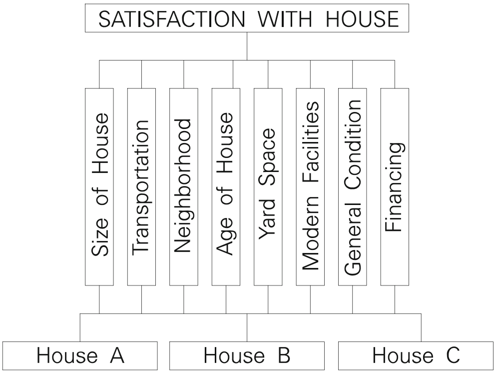


Fig. 1.3 Decomposition of the problem into a hierarchy

the goal, and on the third (or bottom) level are the three candidate houses that are to be evaluated in terms of the criteria on the second level. The definitions of the factor and the pictorial representation of the hierarchy follow.

The factors important to the family are:

1. *Size of House:* Storage space; size of rooms; number of rooms; total area of house.
2. *Transportation:* Convenience and proximity of bus service.
3. *Neighborhood:* Degree of traffic, security, taxes, physical condition of surrounding buildings.
4. *Age of House:* Self-explanatory.
5. *Yard Space:* Includes front, back, and side space, and space shared with neighbors.
6. *Modern Facilities:* Dishwasher, garbage disposal, air conditioning, alarm system, and other such items.
7. *General Condition:* Extent to which repairs are needed; condition of walls, carpet, drapes, wiring; cleanliness.
8. *Financing:* Availability of assumable mortgage, seller financing, or bank financing.

The next step is *comparative judgment*. The elements on the second level are arranged into a matrix and the family buying the house makes judgments about the relative importance of the elements with respect to the overall goal, *Satisfaction with House*.

The questions to ask when comparing two criteria are of the following kind: of the two alternatives being compared, which is considered more important by the family and how much more important is it with respect to family satisfaction with the house, which is the overall goal?

The matrix of pairwise comparisons of the factors given by the home buyers in this case is shown in Table 1.3, along with the resulting vector of priorities. The judgments are entered using the Fundamental Scale, first verbally as indicated in the scale and then associating the corresponding number. The vector of priorities is the principal eigenvector of the matrix. This vector gives the relative priority of the

Table 1.3 Pairwise comparison matrix for level 1

	1	2	3	4	5	6	7	8	Priority vector
1	1	5	3	7	6	6	1/3	1/4	0.173
2	1/5	1	1/3	5	3	3	1/5	1/7	0.054
3	1/3	3	1	6	3	4	6	1/5	0.188
4	1/7	1/5	1/6	1	1/3	1/4	1/7	1/8	0.018
5	1/6	1/3	1/3	3	1	1/2	1/5	1/6	0.031
6	1/6	1/3	1/4	4	2	1	1/5	1/6	0.036
7	3	5	1/6	7	5	5	1	1/2	0.167
8	4	7	5	8	6	6	2	1	0.333

$\lambda_{\max} = 9.669$ C.R. $= 0.169$

factors measured on a ratio scale. That is, these priorities are unique to within multiplication by a positive constant. However, if one ensures that they sum to one they are always unique. In this case financing has the highest priority, with 33% of the influence.

In Table 1.3, instead of naming the criteria, we use the number previously associated with each.

Note for example that in comparing Size of House on the left with Size of House on top, a value of equal is assigned. However, when comparing it with Transportation it is strongly preferred and a 5 is entered in the (1, 2) or first row, second column position. The reciprocal value 1/5 is automatically entered in the (2, 1) position. Again when Size of House in the first row is compared with General Condition in the seventh column, it is not preferred but is moderately dominated by General Condition and a 1/3 value is entered in the (1, 7) position. A 3 is then automatically entered in the (7, 1) position. The consistency ration C.R. is equal to 0.169 and one needs to explore the inconsistencies in the matrix with the help of Expert Choice to locate the most inconsistent one and attempt to improve it if there is flexibility in the judgment. Otherwise, one looks at the second most inconsistent judgment and attempts to improve it and so on.

We now move to the pairwise comparisons of the houses on the bottom level, comparing them pairwise with respect to how much better one is than the other in satisfying each criterion on the second level. Thus there are eight 3×3 matrices of judgments since there are eight elements on level two, and three houses to be pairwise compared for each element. The matrices (Table 1.4) contain the judgments of the family involved. In order to facilitate understanding of the judgments, a brief description of the houses is given below.

House A: This house is the largest of them all. It is located in a good neighborhood with little traffic and low taxes. Its yard space is comparably larger than that of houses B and C. However, its general condition is not very good and it needs cleaning and painting. Also, the financing is unsatisfactory because it would have to be financed through a bank at a high interest.

House B: This house is a little smaller than House A and is not close to a bus route. The neighborhood gives one the feeling of insecurity because of traffic conditions. The yard space is fairly small and the house lacks the basic modern

Table 1.4 Pairwise comparison matrices for level 2

	A	B	C	Normalized priorities	Idealized priorities
Size of house[a]					
A	1	6	8	0.754	1.000
B	1/6	1	4	0.181	0.240
C	1/8	1/4	1	0.065	0.086
Transportation[b]					
A	1	7	1/5	0.233	0.327
B	1/7	1	1/8	0.005	0.007
C	5	8	1	0.713	1.000
Neighborhood[c]					
A	1	8	6	0.745	1.000
B	1/8	1	1/4	0.065	0.086
C	1/6	4	1	0.181	0.240
Age of house[d]					
A	1	1	1	0.333	1.000
B	1	1	1	0.333	1.000
C	1	1	1	0.333	1.000
Yard space[e]					
A	1	5	4	0.674	1.000
B	1/5	1	1/3	0.101	0.150
C	1/4	3	1	0.226	0.335
Modern facilities[f]					
A	1	8	6	0.747	1.000
B	1/8	1	1/5	0.060	0.080
C	1/6	5	1	0.193	0.258
General condition[g]					
A	1	1/2	1/2	0.200	0.500
B	2	1	1	0.400	1.000
C	2	1	1	0.400	1.000
Financing[h]					
A	1	1/7	1/5	0.072	0.111
B	7	1	3	0.650	1.000
C	5	1/3	1	0.278	0.428

[a] $\lambda_{\max} = 3.136$ C.I. = 0.068 C.R. = 0.117
[b] $\lambda_{\max} = 3.247$ C.I. = 0.124 C.R. = 0.213
[c] $\lambda_{\max} = 3.130$ C.I. = 0.068 C.R. = 0.117
[d] $\lambda_{\max} = 3.000$ C.I. = 0.000 C.R. = 0.000
[e] $\lambda_{\max} = 3.086$ C.I. = 0.043 C.R. = 0.074
[f] $\lambda_{\max} = 3.197$ C.I. = 0.099 C.R. = 0.170
[g] $\lambda_{\max} = 3.000$ C.I. = 0.000 C.R. = 0.000
[h] $\lambda_{\max} = 3.065$ C.I. = 0.032 C.R. = 0.056

facilities. On the other hand, its general condition is very good. Also an assumable mortgage is obtainable, which means the financing is good with a rather low interest rate. There are several copies of B in the neighborhood.

House C: House C is very small and has few modern facilities. The neighborhood has high taxes, but is in good condition and seems secure. The yard space

Table 1.5 Synthesis

	1 (0.173)	2 (0.054)	3 (0.188)	4 (0.018)	5 (0.031)	6 (0.036)	7 (0.167)	8 (0.333)		
Distributive mode										
A	0.754	0.233	0.754	0.333	0.674	0.747	0.200	0.072	=	0.396
B	0.181	0.055	0.065	0.333	0.101	0.060	0.400	0.650		0.341
C	0.065	0.713	0.181	0.333	0.226	0.193	0.400	0.278		0.263
Ideal mode										
A	1.00	0.327	1.00	1.00	1.00	1.00	0.500	0.111	=	0.584
B	0.240	0.007	0.086	1.00	0.150	0.080	1.00	1.00		0.782
C	0.086	1.00	0.240	1.00	0.335	0.258	1.00	0.428		0.461

is bigger than that of House B, but is not comparable to House A's spacious surroundings. The general condition of the house is good, and it has a pretty carpet and drapes. The financing is better than for A but not better than for B.

Table 1.4 gives the matrices of the houses and their local priorities with respect to the elements on level two.

The next step is to synthesize the priorities. There are two ways of doing that. One is the distributive mode. In order to establish the composite or global priorities of the houses we lay out in a matrix (Table 1.5) the local priorities of the houses with respect to each criterion and multiply each column of vectors by the priority of the corresponding criterion and add across each row, which results in the composite or global priority vector of the houses. The other way of synthesizing is the ideal mode. Here the priorities of the houses for each criterion are first divided by the largest value among them (Table 1.5). That alternative becomes the ideal and receives a value of 1. One then multiplies by the priority of the corresponding criterion and adds as before. House A is preferred if for example copies of B matter and hence the distributed mode is used. In a large number of situations with 10 criteria and 3 alternatives, the two modes gave the same best choice 92% of the time [7]. House B is the preferred house if the family wanted the best house regardless of other houses and how many copies of it there are in the neighborhood and hence the ideal mode is used.

1.13 Absolute Measurement

1.13.1 Evaluating Employees for Raises

Employees are evaluated for raises. The criteria are Dependability, Education, Experience, and Quality, Each criterion is subdivided into intensities, standards, or subcriteria as shown in Fig. 1.4. Priorities are set for the criteria by comparing them in pairs, and these priorities are then given in a matrix. The intensities are then pairwise compared according to priority with respect to their parent criterion

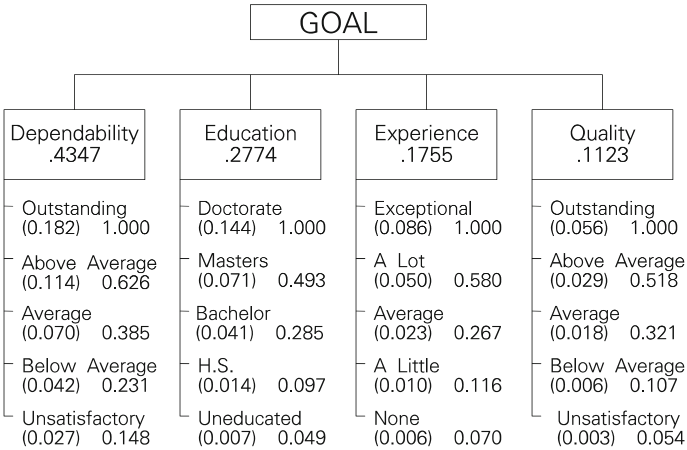


Fig. 1.4 Employee evaluation hierarchy

Table 1.6 Ranking Intensities

	Outstanding	Above average	Average	Below average	Unsatisfactory	Priorities
Outstanding	1.0	2.0	3.0	4.0	5.0	0.419
Above average	1/2	1.0	2.0	3.0	4.0	0.263
Average	1/3	1/2	1.0	2.0	3.0	0.630
Below average	1/4	1/3	1/2	1.0	2.0	0.097
Unsatisfactory	1/5	1/4	1/3	1/2	1.0	0.062

Inconsistency ratio = 0.015

(as in Table 1.6) and their priorities are divided by the largest intensity for each criterion (second column of priorities in Fig. 1.4). Finally, each individual is rated in Table 1.7 by assigning the intensity rating that applies to him or her under each criterion. The scores of these subcriteria are weighted by the priority of that criterion and summed to derive a total ratio scale score for the individual. This approach can be used whenever it is possible to set priorities for intensities of criteria, which is usually possible when sufficient experience with a given operation has been accumulated.

1.13.2 Organ Transplantation

The City of Pittsburgh has become a leader in the world in organ transplantations. Because there are more patients who need livers, hearts and kidneys than there are

Table 1.7 Ranking alternatives

	Dependability 0.4347	Education 0.2774	Experience 0.1775	Quality 0.1123	Total
1. Adams V	Outstanding	Bachelor	A little	Outstanding	0.646
2. Becker L	Average	Bachelor	A little	Outstanding	0.379
3. Hayat F	Average	Masters	A lot	Below average	0.418
4. Kesselman S	Above average	H.S.	None	Above average	0.369
5. O'Shea K	Average	Doctorate	A lot	Above average	0.605
6. Peters T	Average	Doctorate	A lot	Average	0.583
7. Tobias K	Above average	Bachelor	Average	Above average	0.456

available organs, it has become essential to assign priorities to the patients. The priorities shown in the figures are a result of several months of study by Alison R. Casciato and John P. O'Keefe in coordination with doctors and research scientists at a local hospital. Absolute measurement was used for this purpose and is shown in Fig. 1.5a–c. The hierarchy of Fig. 1.5 consists of the goal, the major criteria and subcriteria after which some of the subcriteria are further divided into yet smaller subcriteria or are divided into intensities for rating the patient. Figure 1.5a–c give further subdivision into intensities for those subcriteria in Fig. 1.5 that need to be further subdivide d into intensities. In general, one would use the intensities to score a patient. When there is no intensity, either the full value of the criterion is assigned, or a zero value otherwise. For example, Criminal has 0.033 priority and that value is awarded to a patient with no criminal record. A patient with a criminal record would receive a zero. The goal is divided into: emotionally dependent and financially dependent patients: Both are divided into single, married, and divorced with and without dependent and financially dependent patients. Then each of them is further divided into: medical history (time on donor list, degree of disability), physical history (degree of ability to endure rehabilitation, willingness to cooperate, etc.), and social status (criminal record, volunteer work). The priorities are indicated next to each factor and sum to one for each level. A patient is ranked according to the intensities under each criterion. The higher the total score the better the opportunity to receive a transplant.

1.14 Applications in Industry and Government

In addition to the many illustrations given in this book, the AHP has been used in the economics/management area in subjects including auditing, database selection, design, architecture, finance, macro-economic forecasting, marketing (consumer choice, product design and development, strategy), planning, portfolio selection, facility location, forecasting, resource allocation (budget, energy, health, project), sequential decisions, policy/strategy, transportation, water research, and performance analysis. In political problems, the AHP is used in such areas as arms control, conflicts and negotiation, political candidacy, security assessments, war games, and world influence. For social concerns, it is applied in education,

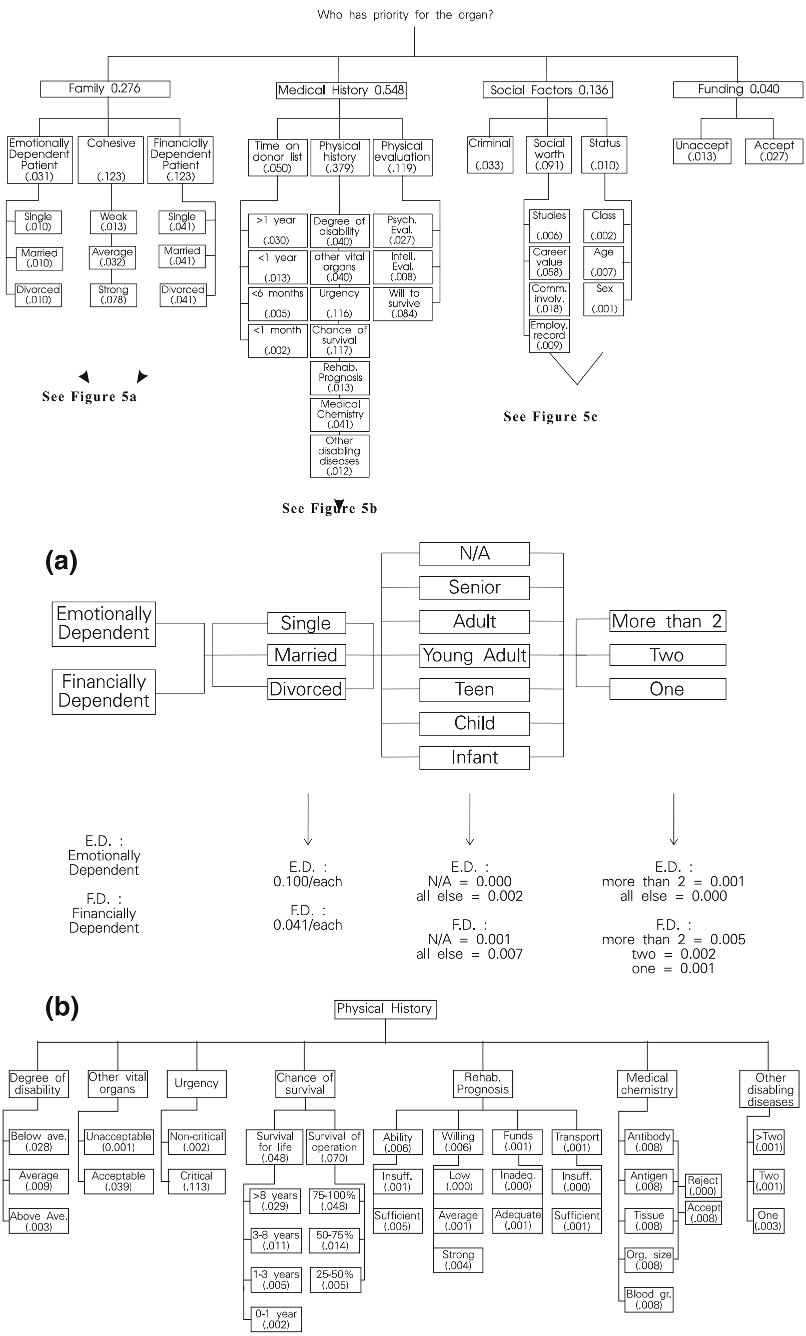
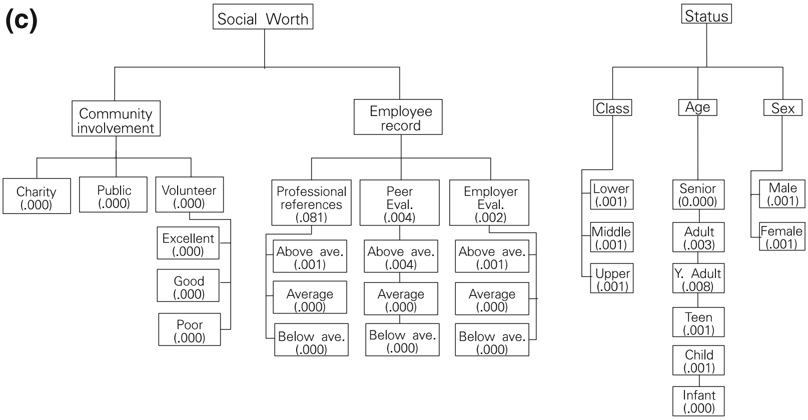


Fig. 1.5 **a** Organ transplantation–family factors. **b** Organ transplantation–medical history factors. **c** Organ transplantation–social factors

(c)



behavior in competition, environmental issues, health, law, medicine (drug effectiveness, therapy selection), population dynamics (interregional migration patterns, population size), and public sector. Some technological applications include market selection, portfolio selection, and technology transfer. Additional applications are discussed in Golden et. al. [3] and Dyer and Forman [1]. For a complete set of references see the bibliography at the end of Ref. [7].

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Chapter 2
The Seven Pillars of the Analytic Hierarchy Process

2.1 Introduction

The Analytic Hierarchy Process (AHP) provides the objective mathematics to process the inescapably subjective and personal preferences of an individual or a group in making a decision. With the AHP and its generalization, the Analytic Network Process (ANP), one constructs hierarchies or feedback networks, then makes judgments or performs measurements on pairs of elements with respect to a controlling element to derive ratio scales that are then synthesized throughout the structure to select the best alternative.

Fundamentally, the AHP works by developing priorities for alternatives and the criteria used to judge the alternatives. Usually the criteria, whose choice is at the mercy of the understanding of the decision-maker (irrelevant criteria are those that are not included in the hierarchy), are measured on different scales, such as weight and length, or are even intangible for which no scales yet exist. Measurements on different scales, of course, cannot be directly combined. First, priorities are derived for the criteria in terms of their importance to achieve the goal, then priorities are derived for the performance of the alternatives on each criterion. These priorities are derived based on pairwise assessments using judgment, or ratios of measurements from a scale if one exists. The process of prioritization solves the problem of having to deal with different types of scales, by interpreting their significance to the values of the user or users. Finally, a weighting and adding process is used to obtain overall priorities for the alternatives as to how they contribute to the goal. This weighting and adding parallels what one would have done arithmetically prior to the AHP to combine alternatives measured under several criteria having the *same* scale (a scale that is often common to several criteria is money) to obtain an overall result. With the AHP a multidimensional scaling problem is thus transformed to a unidimensional scaling problem.

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The seven pillars of the AHP are: (1) **Ratio scales, proportionality, and normalized ratio scales** are central to the generation and synthesis of priorities, whether in the AHP or in any multicriteria method that needs to integrate existing ratio scale measurements with its own derived scales; in addition, ratio scales are the only way to generalize a decision theory to the case of dependence and feedback because ratio scales can be both multiplied, and added—when they belong to the same scale such as a priority scale; when two judges arrive at two different ratio scales for the same problem one needs to test the compatibility of their answers and accept or reject their closeness. The AHP has a non-statistical index for doing this. Ratio scales can also be used to make decisions within an even more general framework involving several hierarchies for benefits, costs, opportunities and risks, and using a common criterion such as *economic* to ensure commensurability; ratio scales are essential in proportionate resource allocation as in linear programming, recently generalized to deal with relative measurement for both the objective function and the constraints obtaining a ratio scale solution vector form which it is possible to decide on the relative values of the allocated resources; one can associate with each alternative a vector of benefits, costs, time of completion, etc., to determine the best alternative subject to all these general concerns; (2) **Reciprocal paired comparisons** are used to express judgments semantically automatically linking them to a numerical fundamental scale of absolute numbers (derived from stimulus response relations) from which the principal eigenvector of priorities is then derived; the eigenvector shows the dominance of each element with respect to the other elements; an element that does not have a particular property is automatically assigned the value zero in the eigenvector without including it in the comparisons; dominance along all possible paths is obtained by raising the matrix to powers and normalizing the sum of the rows; inconsistency in judgment is allowed and a measure for it is provided which can direct the decision maker in both improving judgment and arriving at a better understanding of the problem; scientific procedures for giving less than the full set of $n(n-1)/2$ judgments in a matrix have been developed; using interval judgments eventually leading to the use of optimization and statistical procedures is a complex process which is often replaced by comparing ranges of values of the criteria, performing sensitivity analysis, and relying on conditions for the insensitivity of the eigenvector to perturbations in the judgments; the judgments may be considered as random variables with probability distributions; the AHP has at least three modes for arriving at a ranking of the alternatives: (a) ***Relative***, which *ranks* a few alternatives by comparing them in pairs and is particularly useful in new and exploratory decisions, (b) ***Absolute***, which *rates* an unlimited number of alternatives one at a time on intensity scales constructed separately for each covering criterion and is particularly useful in decisions where there is considerable knowledge to judge the relative importance of the intensities and develop priorities for them; if desired, a few of the top rated alternatives can then be compared against each other using the relative mode to obtain further refinement of the priorities; (c) ***Benchmarking***, which ranks alternatives by including a known alternative in the group and comparing the other against it; (3) **Sensitivity of the principal right eigenvector** to perturbation in judgments limits the number of elements in each set of comparisons to a few and requires that they be homogeneous; the left eigenvector is only meaningful as reciprocal; due to the choice of a unit as one of the two elements in each paired comparison to determine the relative dominance of the second element, it is not possible to derive the principal left eigenvector directly from paired comparisons as the dominant element cannot be decomposed a priori; as a result, to ask for how much less one element is than another we must take the reciprocal of what we get by asking how much more the larger element is; (4) **Homogeneity and clustering** are used to extend the fundamental scale gradually from cluster to adjacent cluster, eventually enlarging the scale from 1–9 to $1-\infty$; (5) **Synthesis that can be extended to dependence and feedback** is applied to the derived ratio scales to create a uni-dimensional ratio scale for representing the overall outcome. Synthesis of the scales derived in the decision structure can only be made to yield correct outcomes on known scales by additive weighting. It should be carefully noted that additive weighting in a hierarchical structure leads to a multilinear form and hence is nonlinear. It is known that under very general conditions such multilinear forms are dense in general function spaces (discrete or continuous), and thus linear combinations of them can be used to approximate arbitrarily close to any nonlinear element in that space. Multiplicative weighting, by raising the priorities of the alternatives to the power of the priorities of the criteria (which it determines through additive weighting!) then multiplying the results, has four major flaws: (a) It does not give back weights of existing same ratio scale measurements on several criteria as it should; (b) It assumes that the matrix of judgments is always consistent, thus sacrificing the idea of inconsistency and how to deal with it, and not allowing redundancy of judgments to improve validity about the real world; (c) Most critically, it does not generalize to the case of interdependence and feedback, as the AHP generalizes to the Analytic Network Process (ANP), so essential for the many decision problems in which the criteria and alternatives depend on each other; (d) It always preserves rank which leads to unreasonable outcomes and contradicts the many counterexamples that show rank reversals should be allowed; (6) **Rank preservation and reversal** can be shown to occur without adding or deleting criteria, such as by simply introducing enough copies of an alternative or for numerous other reasons; this leaves no doubt that rank reversal is as intrinsic to decision making as rank preservation also is; it follows that any decision theory must have at least two modes of synthesis; in the AHP they are called the distributive and ideal modes, with guidelines for which mode to use; rank can always be preserved by using the ideal mode in both absolute measurement and relative measurement; (7) **Group judgments** must be integrated one at a time carefully and mathematically, taking into consideration when desired the experience, knowledge, and power of each person involved in the decision, without the need to force consensus, or to use majority or other ordinal ways of voting; the theorem regarding the *impossibility* of constructing a social utility function from individual utilities that satisfies four reasonable conditions which found their validity with *ordinal* preferences is *no longer true* when *cardinal* ratio scale preferences are used as in the AHP. Instead, one has the *possibility* of constructing such a function. To deal with a large group requires the use of questionnaires and statistical procedures for large samples.

2.2 Ratio Scales

A *ratio* is the relative value or quotient a/b of two quantities a and b *of the same kind*; it is called commensurate if it is a rational number, otherwise it is incommensurate. A statement of the equality of two ratios a/b and c/d is called *proportionality*. A ratio scale is a set of numbers that is invariant under a similarity transformation (multiplication by a positive constant). The constant cancels when the ratio of any two numbers is formed. Either pounds or kilograms can be used to measure weight, but the ratio of the weight of two objects is the same for both scales. An extension of this idea is that the weights of an entire set of objects whether in pounds or in kilograms can be standardized to read the same by normalizing. In general if the readings from a ratio scale are aw_i^*, $i = 1,\ldots,n$, the standard form is given by $w_i = aw_i^*/aw_i^* = w_i^*/w_i^*$ as a result of which we have $w_i = 1$, and the w_i, $i = 1,\ldots,n$, are said to be normalized. We no longer need to specify whether weight for example is given in pounds or in kilograms or in another kind of unit. The weights (2.21, 4.42) in pounds and (1, 2) in kilograms, are both given by (1/3, 2/3) in the standard ratio scale form.

The relative ratio scale derived from a pairwise comparison reciprocal matrix of judgments is derived by solving:

$$\sum_{j=1}^{n} a_{ij}\, w_j = \lambda_{max}\, w_i \tag{2.1}$$

$$\sum_{i=1}^{n} w_i = 1 \tag{2.2}$$

with $a_{ji} = 1/a_{ij}$ or $a_{ij}\, a_{ji} = 1$ (the reciprocal property), $a_{\,ij} > 0$ (thus A is known as a positive matrix) whose solution, known as the principal right eigenvector, is normalized as in (2.2). A relative ratio scale does not need a unit of measurement.

When $a_{ij}\, a_{jk} = a_{ik}$, the matrix $A = (a_{ij})$ is said to be consistent and its principal eigenvalue is equal to n. Otherwise, it is simply reciprocal. The general eigenvalue formulation given in (2.1) is obtained by perturbation of the following consistent formulation:

$$Aw = \begin{array}{c} \\ A_1 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{ccc} A_1 & \cdots & A_n \end{array} \\ \begin{bmatrix} \frac{w_1}{w_1} & \cdots & \frac{w_1}{w_n} \\ \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \end{array} \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = nw.$$

where A has been multiplied on the right by the transpose of the vector of weights $w = (w_{1,\ldots,}w_n)$. The result of this multiplication is nw. Thus, to recover the scale from the matrix of ratios, one must solve the problem $Aw = nw$ or $(A - n\mathrm{I})w = 0$. This is a system of homogeneous linear equations. It has a nontrivial solution if and only if the determinant of $A - n\mathrm{I}$ vanishes, that is, n is an eigenvalue of A. Now A has unit rank since every row is a constant multiple of the first row. Thus all its eigenvalues except one are zero. The sum of the eigenvalues of a matrix is equal to its trace, that is, the sum of its diagonal elements. In this case the trace of A is equal to n. Thus n is an eigenvalue of A, and one has a nontrivial solution. The solution consists of positive entries and is unique to within a multiplicative constant.

The discrete formulation given in (2.1) and (2.2) above generalizes to the continuous case through Fredholm's integral equation of the second kind and is given by:

$$\int_a^b K(s,t)w(t)dt = \lambda_{\max} w(s) \tag{2.3}$$

$$\lambda \int_a^b K(s,t)w(t)dt = w(s) \tag{2.4}$$

$$\int_a^b w(s)ds = 1 \tag{2.5}$$

where instead of the matrix A we have as a positive kernel, $K(s,t) > 0$. Note that the entries in a matrix depend on the two variables i and j which assume discrete values. Thus the matrix itself depends on these discrete variables, and its generalization, the kernel function also depends on two (continuous) variables. The reason for calling it kernel is the role it plays in the integral, where without knowing it we cannot determine the exact form of the solution. The standard way in which (2.3) is written is to move the eigenvalue to the left hand side which gives it the reciprocal form. In general, by abuse of notation, one continues to use the symbol λ to represent the reciprocal value. Our equation for response to a stimulus is now written in the standard form (2.4) with the normalization condition (2.5). Here also, we have the reciprocal property (2.6) and as in the finite case, the kernel $K(s,t)$ is consistent if it satisfies the relation (2.7):

$$K(s,t)K(t,s) = 1 \tag{2.6}$$

$$K(s,t)K(t,u) = K(s,u), \text{ for all } s,\ t, \text{and } u \tag{2.7}$$

An example of this type of kernel is $K(s,t) = \mathrm{e}^{\mathrm{s}-\mathrm{t}} = \mathrm{e}^{\mathrm{s}}/\mathrm{e}^{\mathrm{t}}$. It follows by putting $s = t = u$, that $K(s,s) = 1$ for all s which is analogous to having ones down the diagonal of the matrix in the discrete case. A value of λ for which Fredholm = sequation has a nonzero solution $w(t)$ is called a characteristic value (or its reciprocal is called an eigenvalue) and the corresponding solution is called an eigenfunction. An eigenfunction is determined to within a multiplicative constant. If $w(t)$ is an eigenfunction corresponding to the charateristic value λ and if C is an arbitrary constant, we can easily see by substituting in the equation that $Cw(t)$ is also an eigenfunction corresponding to the same λ. The value $\lambda = 0$ is not a characteristic value because we have the corresponding solution $w(t) = 0$ for every value of t, which is the trivial case, excluded in our discussion.

It may be useful to recount a little of the history of how Fredholm's equation came about in the ratio scale formulation of the AHP. My student Hasan Ait-Kaci and I first recognized the connection between Fredholm's equation and the AHP in a paper we wrote in the late 1970s. In the early 1980s, I and my friend and colleague, Professor Luis Vargas, used this formulation in the framework of neural firing and published several papers on the subject. In December of 1996, I had the nagging idea that the ratio scale relation for electrical firing was not reflected in our solution, and that periodicity had to be involved in the solution with which I began. Many researchers on the brain had considered neural firing in the framework of a damped periodic oscillator. It was my friend Janos Aczel, the leading functional equation mathematician in the world, who provided me with a variety of solutions for the functional equation ($w(as) = bw(s)$). I had proved in the theorem given below that this equation characterizes the solution of Fredholm's equation and its solution is an eigenfunction of that equation. My work is an extension of the work I had done earlier with Vargas. The solution has the form of a damped periodic oscillator of period one. It has an additional logarithmic property that corresponds to Fechner's law discussed later in this paper.

A matrix is consistent if and only if it has the form $A = (w_i/w_j)$ which is equivalent to multiplying a column vector that is the transpose of $(w_1, \ldots, w_n)$ by the row vector $(1/w_1, \ldots, 1/w_n)$. As we see below, the kernel $K(s,t)$ is separable and can be written as

$$K(s,t) = k_1(s)k_2(t).$$

Theorem *$K(s,t)$ is consistent if and only if it is separable of the form:*

$$K(s,t) = k(s)/k(t). \tag{2.8}$$

Theorem *If $K(s,t)$ is consistent, the solution of (2.4) is given by*

$$w(s) = \frac{k(s)}{\int_S k(s)ds}. \tag{2.9}$$

In the discrete case, the normalized eigenvector was independent of whether all the elements of the pairwise comparison matrix A are multiplied by the same constant a or not, and thus we can replace A by aA and obtain the same eigenvector. Generalizing this result we have:

$$K(as, at) = aK(s,t) = k(as)/k(at) = a\,k(s)/k(t)$$

which means that K is a homogeneous function of order one. In general, when $f(ax_1, \ldots, ax_n) = a^n f(x_1, \ldots, x_n)$ holds, f is said to be homogeneous of order n. Because K is a degenerate kernel, we can replace $k(s)$ above by $k(as)$ and obtain $w(as)$. We have now derived from considerations of ratio scales the following condition to be satisfied by a ratio scale:

Theorem *A necessary and sufficient condition for $w(s)$ to be an eigenfunction solution of Fredholm's equation of the second kind, with a consistent kernel that is homogeneous of order one, is that it satisfy the functional equation*

$$w(as) = bw(s)$$

where $b = \alpha a$.

We have for the general damped periodic response function $w(s)$,

$$w(s) = Ce^{\log b \frac{\log s}{\log a}} P\left(\frac{\log s}{\log a}\right)$$

where P is periodic of period 1 and $P(0) = 1$.

We can write this solution as

$$v(u) = C_1 e^{-bu} P(u)$$

where $P(u)$ is periodic of period 1, $u = \log s/\log a$ and $\log ab/-\beta$, $\beta > 0$. It is interesting to observe the logarithmic function appear as part of the solution. It gives greater confirmation to the Weber–Fechner law developed in the next section.

2.3 Paired Comparisons and the Fundamental Scale

Instead of assigning two numbers w_i and w_j and forming the ratio w_i/w_j we assign a single number drawn from the fundamental 1–9 scale of absolute numbers to represent the ratio $(w_i/w_j)/1$. It is a nearest integer approximation to the ratio w_i/w_j. The derived scale will reveal what the w_i and w_j are. This is a central fact about the relative measurement approach of the AHP and the need for a fundamental scale.

In 1846 Weber found, for example, that people while holding in their hand different weights, could distinguish between a weight of 20 g and a weight of 21 g, but could not if the second weight is only 20.5 g. On the other hand, while they could not distinguish between 40 and 41 g, they could between 40 and 42 g, and so on at higher levels. We need to increase a stimulus s by a minimum amount Δs to reach a point where our senses can first discriminate between s and $s + \Delta s$. Δs is called the just noticeable difference (jnd). The ratio $r = \Delta s/s$ does not depend on s. Weber's law states that change in sensation is noticed when the stimulus is increased by a constant percentage of the stimulus itself. This law holds in ranges where Δs is small when compared with s, and hence in practice it fails to hold when s is either too small or too large. Aggregating or decomposing stimuli as needed into clusters or hierarchy levels is an effective way for extending the uses of this law.

In 1860 Fechner considered a sequence of just noticeable increasing stimuli. He denotes the first one by s_0. The next just noticeable stimulus is given by

$$s_1 = s_1 + \Delta s_0 = s_0 + \frac{\Delta s_0}{s_0} s_0 = s_0(1+r)$$

based on Weber‘s law.

Similarly $s_2 = s_1 + \Delta s_1 = s_1(1+r) = s_0(1+r)^2 \equiv s_0\,\alpha^2$. In general $s_n = s_{n-1}\,\alpha = s_0\,\alpha^n (n = 0, 1, 2, \ldots)$.

Thus stimuli of noticeable differences follow sequentially in a geometric progression. Fechner noted that the corresponding sensations should follow each other in an arithmetic sequence at the discrete points at which just noticeable differences occur. But the latter are obtained when we solve for n. We have $n = \frac{(\log s_n - \log s_0)}{\log \alpha}$ and sensation is a linear function of the logarithm of the stimulus. Thus if M denotes the sensation and s the stimulus, the psychophysical law of Weber–Fechner is given by

$$M = a \log\ s + b, \quad a \neq 0.$$

We assume that the stimuli arise in making pairwise comparisons of relatively comparable activities. We are interested in responses whose numerical values are in the form of ratios. Thus $b = 0$, from which we must have log $s_0 = 0$ or $s_0 = 1$, which is possible by calibrating a unit stimulus. Here the unit stimulus is s_0. The next noticeable stimulus is $s_1 = s_0\,\alpha = \alpha$ which yields the second noticeable response a log α. The third noticeable stimulus is $s_2 = s_0\,\alpha^2$ which yields a response of $2a$ log α. Thus we have for the different responses:

$$M_0 = a \log s_0,\ M_1 = a \log \alpha,\ M_2 = 2a \log \alpha, \ldots,\ M_n = na \log \alpha.$$

While the noticeable ratio stimulus increases geometrically, the response to that stimulus increases arithmetically. Note that $M_0 = 0$ and there is no response. By dividing each M_i by M_1 we obtain the sequence of absolute numbers 1, 2, 3,… of the fundamental 1–9 scale. Paired comparisons are made by identifying the less dominant of two elements and using it as the unit of measurement. One then determines, using the scale 1–9 or its verbal equivalent, how many times more the dominant member of the pair is than this unit. In making paired comparisons, we use the nearest integer approximation from the scale, relying on the insensitivity of the eigenvector to small perturbations (discussed below). The reciprocal value is then automatically used for the comparison of the less dominant element with the more dominant one. Despite the foregoing derivation of the scale in the form of integers, someone might think that other scale values would be better, for example using 1.3 in the place of 2. Imagine comparing the magnitude of two people with respect to the magnitude of one person and using 1.3 for how many there are instead of 2.

We note that there may be elements that are closer than 2 on the 1–9 scale, and we need a variant of the foregoing. Among the elements that are close, we select the smallest. Observe the incremental increases between that smallest one and the rest of the elements in the close group. We now consider these increments to be new elements and pairwise compare them on the scale 1–9. If two of the increments are themselves closer than 2 we treat them as identical, assigning a 1 (we could carry this on ad infinitum—but we will not). In the end each component of the eigenvector of comparisons of the increments is added to unity to yield the un-normalized priorities of the close elements for that criterion. Note that only the least of these close elements is used in comparisons with the other elements that can be compared directly using the normal 1–9 scale. Its priority is used to multiply the priorities of these close elements and finally the priorities of all the elements are re-normalized.

How large should the upper value of the scale be? Qualitatively, people have a capacity to divide their response to stimuli into three categories: high, medium and low. They also have the capacity to refine this division by further subdividing each of these intensities of responses into high, medium and low, thus yielding in all nine subdivisions. It turns out, from the requirement of homogeneity developed below, that to maintain stability, our minds work with a few elements at a time. Using a large number of elements in one matrix leads to greater inconsistency.

2.4 Sensitivity of the Principal Eigenvector Places a Limit on the Number of Elements and Their Homogeneity

To a first order approximation, perturbation Δw_1 in the principal eigenvector w_1 due to a perturbation ΔA in the matrix A where A is consistent is given by:

$$\Delta w_1 = \sum_{j=2}^{n} (v_j^T \, \Delta A \, w_1 \, / (\lambda_1 - \lambda_j) \, v_j^T \, w_j) \, w_j \, .$$

The eigenvector w_1 is insensitive to perturbation in A, if the principal eigenvalue λ_1 is separated from the other eigenvalues λj, here assumed to be distinct, and none of the products $v_{\mathrm{j}}^{\mathrm{T}}\ w_{\mathrm{j}}$ of left and right eigenvectors is small. We should recall that the nonprincipal eigenvectors need not be positive in all components, and they may be complex. One can show that all the $v_{\mathrm{j}}^{\mathrm{T}}\ w_{\mathrm{j}}$ are of the same order, and that $v_1^{\mathrm{T}}\ w_{1,}$ the product of the normalized left and right principal eigenvectors is equal to n. If n is relatively small and the elements being compared are homogeneous, none of the components of w_1 is arbitrarily small and correspondingly, none of the components of v_1^{T} is arbitrarily small. Their product cannot be arbitrarily small, and thus w is insensitive to small perturbations of the consistent matrix A. The conclusion is that n must be small, and one must compare homogeneous elements. Later we discuss placing a limit on the value of n.

2.5 Clustering and Using Pivots to Extend the Scale from 1–9 to 1–∞

In Fig. 2.1, an unripe cherry tomato is eventually and indirectly compared with a large watermelon by first comparing it with a small tomato and a lime, the lime is then used again in a second cluster with a grapefruit and a honey dew where we then divide by the weight of the lime and then multiply by its weight in the first cluster, and then use the honey dew again in a third cluster and so on. In the end we have a

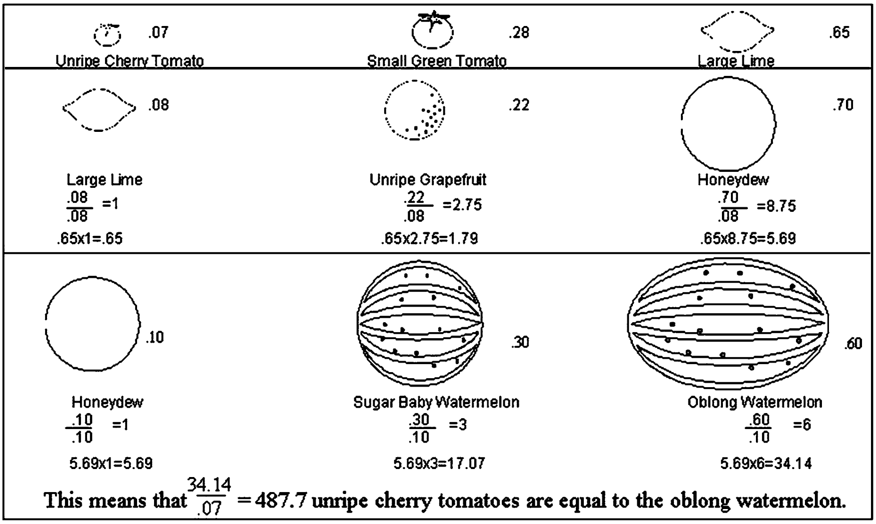

Fig. 2.1 Clustering

comparison of the unripe cherry tomato with the large watermelon and would accordingly extended the scale from 1–9 to 1–721.

Such clustering is essential, and must be done separately for each criterion. We should note that in most decision problems, there may be one or two levels of clusters and conceivably it may go up to three or four adjacent ranges of homogeneous elements (Maslow put them in seven groupings). Very roughly we have in decreasing order of importance: (1) Survival, health, family, friends and basic religious beliefs some people were known to die for; (2) Career, education, productivity and lifestyle; (3) Political and social beliefs and contributions; (4) Beliefs, ideas, and things that are flexible and it does not matter exactly how one advocates or uses them. Nevertheless one needs them, such as learning to eat with a fork or a chopstick or with the fingers as many people do interchangeably. These categories can be generalized to a group, a corporation, or a government. For very important decisions, two categories may need to be considered. Note that the priorities in two adjacent categories would be sufficiently different, one being an order of magnitude smaller than the other, that in the synthesis, the priorities of the elements in the smaller set have little effect on the decision. We do not have space to show how some *undesirable* elements can be compared among themselves and gradually extended to compare them with *desirable* ones as above. Thus one can go from negatives to positives but keep the measurement of the two types positive, by eventually clustering them separately.

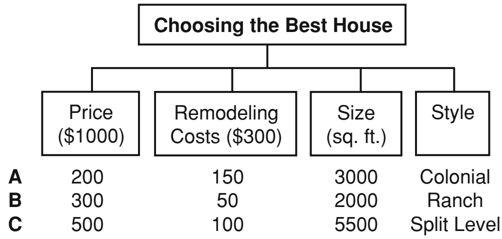

Fig. 2.2 Ranking houses on four criteria

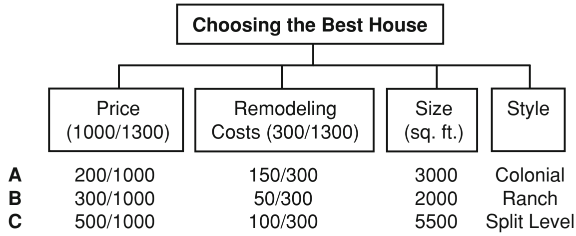

Fig. 2.3 Normalization of the measurements

2.6 Synthesis: How to Combine Tangibles With Intangibles—Additive Versus Multiplicative

Let H be a complete hierarchy with h levels. Let B_k be the priority matrix of the kth level, $k = 2,\ldots, h$. If W' is the global priority vector of the pth level with respect to some element z in the (p − 1)st level, then the priority vector W of the qth level ($p < q$) with respect to z is given by the multilinear (and thus non-linear) form,

$$W = B_q\, B_{q-1} \ldots B_{p+1}\, W'.$$

The global priority vector of the lowest level with respect to the goal is given by,

$$W = B_h\, B_{h-1} \ldots B_2\, W'.$$

In general, $W' = 1$. The sensitivity of the bottom level alternatives with respect to changes in the weights of elements in any level can be studied by means of this multilinear form.

Assume that a family is considering buying a house and there are three houses to consider A, B, and C. Four factors dominate their thinking: the price of the house, the remodeling costs, the size of the house as reflected by its footage and the style of the house which is an intangible. They have looked at three houses with numerical data shown below on the quantifiables (Fig. 2.2):

If we add the costs on price and modeling and normalize we obtain respectively (A, B, C) = (0.269, 0.269, 0.462). Now let us see what is needed for normalization to yield the same result.

First we normalize for each of the quantifiable factors. Then we must normalize the factors measured with respect to a single scale (Fig. 2.3).

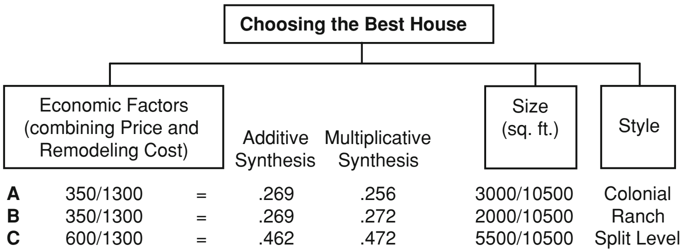

Fig. 2.4 Combining the two costs through additive or multiplicative syntheses

Here we learn two important lessons to be used in the general approach. Normalizing the alternatives for the two criteria involving money in terms of the money involved on both criteria leads to relative weights of importance for the criteria. Here for example Price is in the ratio of about three to one when compared with Remodeling Cost and when compared with the latter with respect to the goal of choosing the best house, it is likely to be assigned the value "moderate" which is nearly three times more as indicated by the measurements. Here the criteria Price and Remodeling Cost derive their priorities only from the alternatives because they are equally important factors, although they can also acquire priorities from higher level criteria as to their functional importance with respect to the ease and availability of different amounts of money. We now combine the two factors with a common scale by weighting and adding. We have (Fig. 2.4):

The left column and its decimal values in the second column give the exact value of the normalized dollars spent on each house obtained by additive synthesis (weighting and adding). By aggregating the two factor measured with dollars into a single factor, one then makes the decision as to which house to buy by comparing the three criteria as to their importance with respect to the goal.

The second lesson is that *when the criteria have different measurements, their importance cannot be determined from the bottom up through measurement of the alternatives, but from the top down, in terms of the goal. The same process of comparison of the criteria with respect to the goal is applied to all criteria if, despite the presence of a physical scale, they are assumed to be measurable on different scales as they might when actual values are unavailable or when it is thought that such measurement does not reflect the relative importance of the alternatives with respect to the given criterion. Imagine that no physical scale of any kind is known!* We might note in passing that the outcome of this process of comparison with respect to higher level criteria yields meaningful (not arbitrary) results as noted by two distinguished proponents of multi-attribute value theory (MAVT) Buede and Maxwell [1], who wrote about their own experiments in decision making:

> These experiments demonstrated that the MAVT and AHP techniques, when provided with the same decision outcome data, very often identify the same alternatives as 'best'. The other techniques are noticeably less consistent with MAVT, the Fuzzy algorithm being the least consistent.

Multiplicative synthesis, as in the third column of numbers above, done by raising each number in the two columns in the previous table to the power of its criterion measured in the relative total dollars under it, multiplying the two outcomes for each alternative and normalizing, *does not* yield the *exact answer* obtained by adding dollars! In addition, A and B should have the same value, but they do not with multiplicative synthesis. The multiplicative "solution" devised for the fallacy of always preserving rank and avoiding inconsistency fails, because it violates the most basic of several requirements mentioned in the introduction to this paper.

Multiplicative and additive syntheses are related analytically through approximation. If we denote by a_i the priority of the ith criterion, i = 1,…,n, and by x_i, the priority of alternative x with respect to the ith criterion, then

$$\begin{aligned}\prod x_i^{a_i} &= \exp \log \prod x_i^{a_i} = \exp(\sum \log x_i^{a_i}) = \exp(\sum a_i \log x_i) \\ &\approx 1 + \sum a_i \log x_i \approx 1 + \sum (a_i x_i - a_i) = \sum a_i x_i\end{aligned}$$

If desired, one can include a remainder term to estimate the error. With regard to additive and multiplicative syntheses being close, one may think that in the end it does not matter which one is used, but it does. Saaty and Hu [7] have shown that despite such closeness on every matrix of consistent judgments in a decision, the synthesized outcomes by the two methods not only lead to different final priorities (which can cause a faulty allocation of resources) but more significantly to *different rankings* of the alternatives. For all these problems, but more significantly because it does not generalize to dependence and feedback even with consistency guaranteed, and because of the additive nature of matrix multiplication needed to compute feedback in network circuits to extend the AHP to the ANP, I do not recommend ever using multiplicative synthesis. It can lead to an undesirable ranking of the alternatives of a decision.

2.7 Rank Preservation and Reversal

Given the assumption that the alternatives of a decision are completely independent of one another, can and should the introduction (deletion) of new (old) alternatives change the rank of some alternatives without introducing new (deleting old) criteria, so that a less preferred alternative becomes most preferred? Incidentally, how one prioritizes the criteria and subcriteria is even more important than how one does the alternatives which are themselves composites of criteria. Can rank reverse among the criteria themselves if new criteria are introduced? Why should that not be as critical a concern? The answer is simple. In its original form utility theory assumed that criteria could not be weighted and the only important elements in a decision were the alternatives and their utilities under the various criteria. Today utility theorists imitate the AHP by rating, and some even by comparing the criteria, somehow. There was no concern then about what would happen to the ranks of the alternatives should the criteria weights themselves change as there were none. The tendency, even today, is to be unconcerned about the theory of rank preservation and reversal among the criteria themselves.

The house example of the previous section teaches us an important lesson. If we add a fourth house to the collection, the priority weights of the criteria Price and Remodeling Cost would change accordingly. Thus the measurements of the alternatives and their number, which we call structural factors, always affect the importance of the criteria. When the criteria are incommensurate and their functional priorities are determined in terms of yet higher level criteria or goals, one must still weight such functional importance of the criteria by the structural effect of the alternatives. What is significant in all this is that the importance of the criteria always depends on the measurements of the alternatives. If we assume that the alternatives are measured on a different scale for each criterion, it becomes obvious that normalization is the instrument that provides the structural effect to update the importance of the criteria in terms of what alternatives there are. Finally, the priorities of the alternatives are weighted by the priorities of the criteria that depend on the measurements of the alternatives. This implies that the overall ranking of any alternative depends on the measurement and number of all the alternatives. To always preserve rank means that the priorities of the criteria should not depend on the measurements of the alternatives but should only derive from their own functional importance with respect to higher goals. This implies that the alternatives should not depend on the measurements of other alternatives. Thus one way to always preserve rank is to rate the alternatives one at a time. In the AHP this is done through absolute measurement with respect to a complete set of intensity ranges with the largest value intensity value equal to one. It is also possible to preserve rank in relative measurement by using an ideal alternative with full value of one for each criterion.

The logic about what can or should happen to rank when the alternatives *depend* on each other has always been that *anything* can happen. Thus, when the criteria functionally depend on the alternatives, which implies that the alternatives, which of course depend on the criteria, would then depend on the alternatives themselves, rank may be allowed to reverse. The Analytic Network Process (ANP) is the generalization of the AHP to deal with ranking alternatives when there is functional dependence and feedback of any kind. Even here, one can have a decision problem with dependence among the criteria, but with no dependence of criteria on alternatives and rank may still need to be preserved. The ANP takes care of functional dependence, but if the criteria do not depend on the alternatives, the latter are kept out of the supermatrix and ranked precisely as they are dealt with in a hierarchy [8].

Examples of rank reversal abound in practice, and they do not occur because new criteria are introduced. The requirement that rank always be preserved or that it should be preserved with respect to irrelevant alternatives. To every rule or generalization that one may wish to set down about rank, it is possible to find a counterexample that violates that rule. Here is the last and most extreme form of four variants of an attempt to qualify what should happen to rank given by Luce and Raiffa, each of which is followed by a counterexample. They state it but and then reject it. *The addition of new acts to a decision problem under uncertainty never changes old, originally non-optimal acts into optimal ones. The all-or-none feature of the last form may seem a bit too stringent… a severe criticism is that it yields unreasonable results.* The AHP has a theory and implementation procedures and guidelines for when to preserve rank and when to allow it to reverse. One mode of the AHP allows an irrelevant alternative to cause reversal among the ranks of the original alternatives.

2.7.1 Guidelines for Selecting the Distributive or Ideal Mode

The distributive mode of the AHP produces preference scores by normalizing the performance scores; it takes the performance score received by each alternative and divides it by the sum of performance scores of all alternatives under that criterion. This means that with the Distributive mode the preference for any given alternative would go up if we reduce the performance score of another alternative or remove some alternatives.

The Ideal mode compares each performance score to a fixed benchmark such as the performance of the best alternative under that criterion. This means that with the Ideal mode the preference for any given alternative is independent of the performance of other alternatives, except for the alternative selected as a benchmark. Saaty and Vargas [11] have shown by using simulation, that there are only minor differences produced by the two synthesis modes. This means that the decision should select one or the other if the results diverge beyond a given set of acceptable data.

The following guidelines were developed by Millet and Saaty [3] to reflect the core differences in translating performance measures to preference measures of alternatives. *The Distributive* (*dominance*) *synthesis mode should be used when the decision maker is concerned with the extent to which each alternative* <u>*dominates*</u> *all other alternatives under the criterion. The Ideal* (*performance*) *synthesis mode should be used when the decision maker is concerned with how well each alternative* <u>*performs*</u> *relative to a fixed benchmark.* In order for dominance to be an issue the decision-maker should regard inferior alternatives as relevant even after the ranking process is completed. This suggests a simple test for the use of the Distributive mode: *if the decision maker indicates that the preference for a top ranked alternative under a given criterion would improve if the performance of any lower ranked alternative was adjusted downward, then one should use the Distributive synthesis mode.* To make this test more actionable we can ask the decision maker to imagine the amount of money he or she would be willing to pay for the top ranked alternative. If the decision maker would be willing to pay more for a top ranked alternative after learning that the performance of one of the lower-ranked alternatives was adjusted downward, then the Distributive mode should be used.

Consider selecting a car: Two different decision makers may approach the same problem from two different points of views even if the criteria and standards are the same. The one who is interested in "getting a well performing car" should use the Ideal mode. The one who is interested in "getting a car that stands out" among the alternatives purchased by co-workers or neighbors, should use the Distributive mode.

2.8 Group Decision Making

Here we consider two issues in group decision making. The first is how to aggregate individual judgments, and the second is how to construct a group choice from individual choices.

2.8.1 How to Aggregate Individual Judgments

Let the function $f(x_1, x_2,\ldots, x_n)$ for synthesizing the judgments given by n judges, satisfy the

1. *Separability condition* (S): $f(x_1, x_2,\ldots,x_n) = g(x_1)g(x_2)\ldots g(x_n)$ for all $x_1, x_2,\ldots,x_n$ in an interval P of positive numbers, where g is a function mapping P onto a proper interval J and is a continuous, associative and cancellative operation. [(S) means that the influences of the individual judgments can be separated as above.]
2. *Unanimity condition* (U): $f(x, x,\ldots,x) = x$ for all x in P. [(U) means that if all individuals give the same judgment x, that judgment should also be the synthesized judgment.]
3. *Homogeneity condition* (H): $f(ux_1, ux_2,\ldots,ux_n) = uf(x_1, x_2,\ldots,x_n)$ where $u > 0$ and x_k, ux_k $(k = 1,2,\ldots,n)$ are all in P. [For ratio judgments (H) means that if all individuals judge a ratio u times as large as another ratio, then the synthesized judgment should also be u times as large.]
4. *Power conditions* (P_p): $f(x_1^p,x_2^p,\ldots,x_n^p) = f^p(x_1, x_2,\ldots,x_n)$. [($P_2$) for example means that if the kth individual judges the length of a side of a square to be x_k, the synthesized judgment on the area of that square will be given by the square of the synthesized judgment on the length of its side.]

Special case ($R = P_{-1}$): $f(1/x_1, 1/x_2,\ldots,1/x_n) = 1/f(x_1, x_2,\ldots,x_n)$. [(R) is of particular importance in ratio judgments. It means that the synthesized value of the reciprocal of the individual judgments should be the reciprocal of the synthesized value of the original judgments.]

Aczel and Saaty (see [9, 10]) proved the following theorem:

Theorem *The general separable* (*S*) *synthesizing functions satisfying the unanimity* (*U*) *and homogeneity* (*H*) *conditions are the geometric mean and the root-mean-power*. If moreover the reciprocal property (R) is assumed even for a single n-tuple $(x_1, x_2,\ldots,x_n)$ of the judgments of n individuals, where not all x_k are equal, then only the geometric mean satisfies all the above conditions.

In any rational consensus, those who know more should, accordingly, influence the consensus more strongly than those who are less knowledgeable. Some people are clearly wiser and more sensible in such matters than others, others may be more powerful and their opinions should be given appropriately greater weight. For such unequal importance of voters not all g's in (S) are the same function. In place of (S), the weighted separability property (WS) is now: $f(x_1, x_2,\ldots,x_n) = g_1(x_1)g_2(x_2)\ldots g_n(x_n)$. [(WS) implies that not all judging individuals have the same weight when the judgments are synthesized and the different influences are reflected in the different functions ($g_1, g_2,\ldots,g_n$).]

In this situation, Aczel and Alsina (see [9]) proved the following theorem:

Theorem *The general weighted-separable* (*WS*) *synthesizing functions with the unanimity* (*U*) *and homogeneity* (*H*) *properties are the weighted geometric mean* $f(x_1, x_2, \ldots, x_n) = x_1^{q_1} x_2^{q_2} \ldots x_n^{q_n}$ *and the weighted root-mean-powers* $f(x_1, x_2, \ldots, x_n) = \sqrt[\gamma]{q_1 x_1^\gamma + q_2 x_2^\gamma \ldots + q_n x_n^\gamma}$, *where* $q_1 + q_2 + \ldots + q_n = 1$, $q_k > 0$ ($k = 1,2,\ldots,n$), $\gamma > 0$, *but otherwise* $q_1,q_2,\ldots,q_n$, γ *are arbitrary constants.*

If f also has the reciprocal property (R) and for a single set of entries ($x_1,x_2,\ldots,x_n$) of judgments of n individuals, where not all x_k are equal, then *only the weighted geometric mean* applies. We give the following theorem which is an explicit statement of the synthesis problem that follows from the previous results, and applies to the second and third cases of the deterministic approach:

Theorem *If* $x_1^{(i)}, \ldots, x_n^{(i)}$ $i = 1,\ldots, m$ *are rankings of n alternatives by m independent judges and if* a_i *is the importance of judge i developed from a hierarchy for evaluating the judges, and hence* $\sum_{i=1}^{m} a_i = 1$, *then* $\left(\prod_{i=1}^{m} x_l^{a_i}\right), \ldots, \left(\prod_{i=1}^{m} x_n^{a_i}\right)$ *are the combined ranks of the alternatives for the m judges.*

The power or priority of judge *i* is simply a replication of the judgment of that judge (as if there are as many other judges as indicated by his/her power a_i), which implies multiplying his/her ratio by itself a_i times, and the result follows.

The first requires knowledge of the functions which the particular alternative performs and how well it compares with a standard or benchmark. The second requires comparison with the other alternatives to determine its importance.

2.8.2 On the Construction of Group Choice from Individual Choices

Given a group of individuals, a set of alternatives (with cardinality greater than (2), and individual ordinal preferences for the alternatives, Arrow proved with his Impossibility Theorem that it is impossible to derive a rational group choice (construct a social choice function that aggregates individual preferences) from ordinal preferences of the individuals that satisfy the following four conditions, i.e., at least one of them is violated:

Decisiveness: the aggregation procedure must generally produce a group order.
Unanimity: if all individuals prefer alternative A to alternative B, then the aggregation procedure must produce a group order indicating that the group prefers A to B.
Independence of irrelevant alternatives: given two sets of alternatives which both include A and B, if all individuals prefer A to B in both sets, then the aggregation procedure must produce a group order indicating that the group, given any of the two sets of alternatives, prefers A to B.
No dictator: no single individual preferences determine the group order.

Using the ratio scale approach of the AHP, it can be shown that because now the individual preferences are cardinal rather than ordinal, it is possible to derive a rational group choice satisfying the above four conditions. It is possible because: (a) Individual priority scales can always be derived from a set of pairwise cardinal preference judgments as long as they form at least a minimal spanning tree in the completely connected graph of the elements being compared; and (b) The cardinal preference judgments associated with group choice belong to a ratio scale that represents the relative intensity of the group preferences.

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Chapter 3
Architectural Design

3.1 Introduction

This chapter illustrates the use of the Analytic Hierarchy Process in determining the amount and location of space assigned to each room, according to its function, in the design of a house [1].

We develop the plan of a house to satisfy a family's needs by considering the size of the lot, the size and shape of the different architectural spaces, their priorities, and their overall contiguity. We begin by identifying needs and then integrating them with the final plan by relating shape, size, geometric design and location to our mental criteria and personal needs. This approach also permits one to treat all these needs and their relation to the environment in a coherent framework.

We study design by addressing six basic factors: (1) architectural needs; (2) Budget allocation; (3) allocation of areas to satisfy needs; (4) size and shape of the areas; (5) clustering spaces according to general needs; (6) identifying and locating individual spaces in each cluster.

We assume that in this hypothetical example we are dealing with the needs of a family of three, the husband (H), the wife (W), and their child (CH). They already own a fully paid lot, on which they wish to build a custom designed house (see Fig. 3.1). The husband and wife have a maximum total disposable budget of \$70,000 to cover construction and landscaping improvement costs. Other costs such as legal fees, architectural fees, permits, etc. are not included. The cost of construction is assumed to be \$30 per square foot and that of landscaping \$1.20 per square foot. (The matrices of judgments are included for completeness.)

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DOI: 10.1007/978-1-4614-3597-6_3,

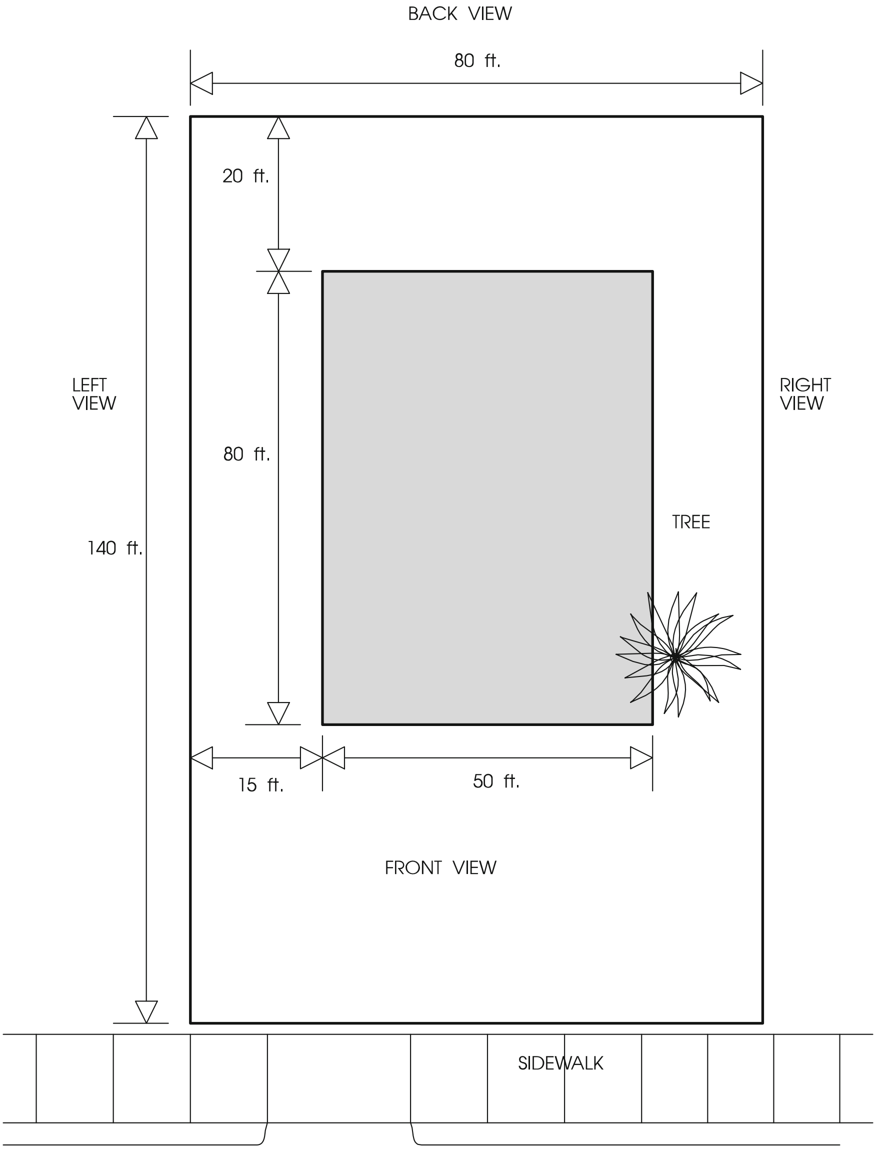

Fig. 3.1 The lot

3.2 Architectural Needs

The members of the family are considered to be the actors or decision makers. The parents will exercise far greater influence than the child on the design process. Since each of them will be seeking to satisfy similar human needs expressed

Table 3.1 Power of the parties

	W	H	CH	Eigenvector	Revised power
W	1	2	4	0.547	0.613
H	1/2	1	4	0.387	0.387
CH	1/4	1/4	1	0.109	0.000

$\lambda_{\max} = 3.054$, C.R. $= 0.05$

through architectural design, we will consider their objectives to be the same, the difference being that each party may assign a different weight to each objective. These objectives are: (1) The need to eat (M); (2) The need to rest (R); (3) The need to entertain (E); (4) The need to clean (K); (5) The need to store (S); (6)The need to communicate, e.g., through halls and entrance, within the house (C).

First we develop a set of priorities indicating the relative power of the parties in determining the outcome for the above architectural needs (see Table 3.1). Table 3.1 consists of calculations done for the parties. The table shows that the child will not influence decisions greatly, even if the husband were to enter a full coalition with him. In our estimate in this hypothetical example, combining both parties would only increase their joint power slightly (0.453), but they would still be unable to surpass the power of the wife (0.547). Because of this fact, we eliminate the child from further consideration of influence, and focus on the husband (H) and wife (W) as the sole representatives of the family needs.

Next, we prioritize the importance of the objectives from the standpoints of W and H (Table 3.2). We then weight each outcome by the power of the corresponding party (see the last column of Table 3.2), and take the sum of the composite outcomes (see Table 3.2a and Fig. 3.2). This sum will be used to allocate square footage to each architectural space for each objective.

Next, a predetermined array of architectural spaces are assigned to each party, arranged in such a way as to satisfy one or more of the above objectives. For example, the family room can be placed in such a way as to satisfy entertainment and resting needs (see Fig. 3.2). The parties will be allowed to change or modify their estimate of the importance of these functions. We then pairwise compare these spaces with respect to the six objectives listed above, to determine what each party's preference is to satisfy its particular objectives. This yields weights or priorities for the space assigned. This prioritization can be revised after later negotiations among the parties, in order to reach an acceptable compromise solution. The results are shown in Tables 3.3 and 3.4. We note from these comparisons, that H and W have widely differing preferences for the space assigned within each objective. This is reflected in their priorities for the spaces also shown in the tables. These preferences are then weighted by the priority of the objective for that party and by the power of the party, i.e., we use the last column of Table 3.2 to obtain the last columns of Tables 3.3 and 3.4. Table 3.5 gives the sum of the priorities of the spaces for H and W.

Table 3.2 Strength of objectives

Party: Wife (Power of party 0.613)[a]

	R	M	E	K	S	C	Eigenvector	Objectives adjusted for power
R	1	0.50	0.33	4	6	6	0.198	0.121
M	2	1	0.33	3	4	4	0.206	0.127
E	3	3	1	6	7	7	0.424	0.260
R	0.25	0.33	0.17	1	4	5	0.096	0.059
M	0.17	0.25	0.14	0.25	1	1	0.038	0.023
E	0.17	0.25	0.14	0.20	1	1	0.037	0.023

Party: Husband (Power of party 0.387)[b]

	R	M	E	K	S	C	Eigenvector	Objectives adjusted for power
R	1	2	0.33	5	6	6	0.247	0.096
M	0.50	1	0.33	4	5	5	0.176	0.068
E	3	3	1	6	8	8	0.440	0.170
R	0.20	0.25	0.17	1	1	1	0.049	0.019
M	0.17	0.20	0.13	1	1	1	0.044	0.017
E	0.17	0.20	0.13	1	1	1	0.044	0.017

(a) Combined weight of objectives

	Wife	Husband	Combined weight
R	0.121	0.096	0.217
M	0.127	0.068	0.195
E	0.260	0.170	0.430
D	0.059	0.019	0.078
S	0.023	0.017	0.040
C	0.023	0.017	0.040

[a] $\lambda_{\max} = 6.456$, C.R. $= 0.07$
[b] $\lambda_{\max} = 6.141$, C.R. $= 0.02$

3.3 Allocation of the Budget, Property and Architectural Spaces

From the total budget of $70,000, H and W must decide on the proportion they would like to allocate to construction and to exterior improvement. With the assistance of an architect, they both agree to allocate 85% or nearly $60,000 to Construction and the remainder to Landscaping.

We now proceed to allocating a proportion of the area to each objective. With the $60,000 budget and construction cost of $30 per sq. ft., we calculate that the house would have a maximum area of 2000 sq. ft. Table 3.2a gives the parties' joint preference priorities of the importance of each objective. These priorities are now used to proportionately allocate the 2000 sq. ft. among the objectives, as shown in Table 3.6 below.

Next, we use each party's preferences to assess the size of the architectural space associated with each objective (determined previously in Table 3.5). Here the question we answer through pairwise comparisons is as follows: How does a party

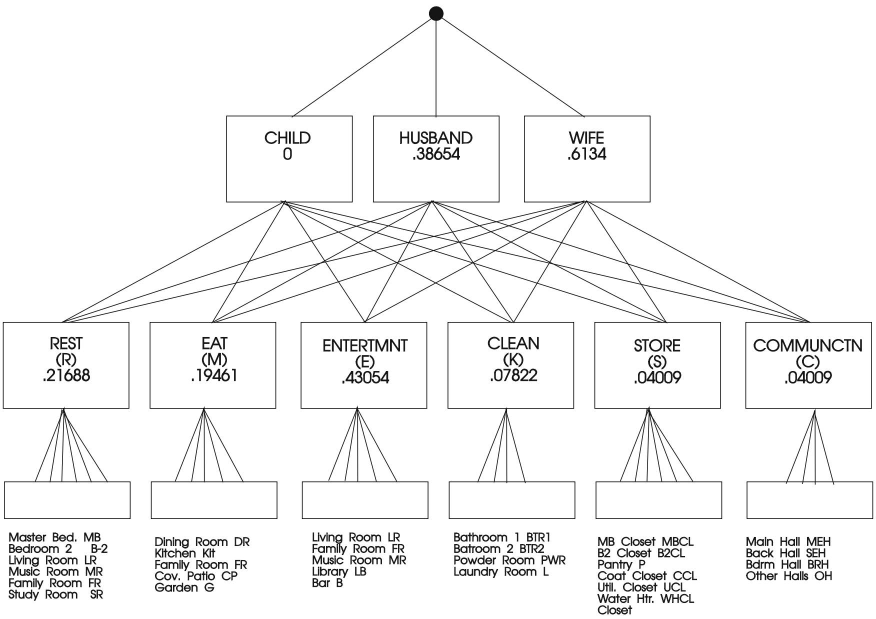

Fig. 3.2 Space prioritization hierarchy

evaluate the size of a particular space, as compared with the size of other spaces within the same objective, in order to obtain a fair split of spaces for that objective? The preferences are shown in Tables 3.7 and 3.8. There, we also weight the resulting priorities by the power of each party (see last columns of Tables 3.7 and 3.8).

The combined overall weight for each space in each objective is the sum of these for each party, as shown in Table 3.9. The last column of Table 3.9 gives the space allocated to each architectural space within each objective, by multiplying the previous column entries by the total square footage allotted to each objective from Table 3.6.

3.4 Dimensions

The choice of dimensions for the rooms (measured in feet) can be made by hierarchical analysis if we have no idea of what is wanted. However, in general people formulate notions about these needs from the environment in which they live. They would make adjustments on what they already know and have experienced. To unfold that complexity of feelings in a hierarchy would be superfluous. Thus, the shape and dimensions of the rooms given in this chapter is an expression of our feelings as what a family of three would require and how each choice would fit with the dimensions of other rooms, whose dimensions are known, to obtain efficient use of each space and proper balance in functionality and aesthetics. For

Table 3.3 Wife's priorities of architectural spaces

Objective: Rest (Weight of objective—Wife: 0.121)[a]

	MB	B-2	LR	SR	MR	FR	Eigenvector	Adjusted for power
MB	1	3	6	5	5	7	0.428	0.052
B-2	0.33	1	7	8	8	6	0.337	0.041
LR	0.17	0.14	1	2	2	1	0.072	0.009
SR	0.20	0.13	0.50	1	1	3	0.065	0.008
MR	0.20	0.13	0.50	1	1	1	0.050	0.006
FR	0.14	0.17	1	0.33	1	1	0.048	0.006

Objective: Eat (Weight of objective—Wife: 0.127)[b]

	DR	FR	KIT	CP	G	Eigenvector	Adjusted for power
DR	1	4	6	4	5	0.511	0.065
FR	0.25	1	5	1	2	0.179	0.023
KIT	0.17	0.20	1	0.33	0.25	0.046	0.006
CP	0.25	1	3	1	0.50	0.120	0.015
G	0.20	0.50	4	2	1	0.144	0.018

Objective: Entertainment (Weight of objective—Wife: 0.260)[c]

	LR	FR	MR	LB	B	Eigenvector	Adjusted for power
LR	1	4	5	5	4	0.495	0.129
FR	0.25	1	4	5	5	0.273	0.071
MR	0.20	0.25	1	1	2	0.089	0.023
LB	0.20	0.20	1	1	0.50	0.064	0.017
B	0.25	0.20	0.50	2	1	0.080	0.021

Objective: Clean (Weight of objective—Wife: 0.059)[d]

	BTR1	BTR2	PWR	L	Eigenvector	Adjusted for power
BTR1	1	4	5	6	0.589	0.035
BTR2	0.25	1	3	4	0.233	0.014
PWR	0.20	0.33	1	3	0.118	0.007
L	0.17	0.25	0.33	1	0.061	0.004

Objective: Store (Weight of objective—Wife: 0.023)[e]

	MBCL	B2CL	P	CCL	UCL	WHCL	Eigenvector	Adjusted for power
MBCL	1	3	3	5	2	6	0.371	0.009
B2CL	0.33	1	4	5	1	3	0.228	0.005
P	0.33	0.25	1	4	1	3	0.131	0.003
CCL	0.20	0.20	0.25	1	0.25	1	0.047	0.001
UCL	0.50	1	1	4	1	3	0.168	0.004
WHCL	0.17	0.33	0.33	1	0.33	1	0.054	0.001

Objective: Communicate (Weight of objective—Wife: 0.023)[f]

	MEH	SEH	BRH	OH	Eigenvector	Adjusted for power
MEH	1	5	4	6	0.591	0.014
SEH	0.20	1	0.33	0.50	0.076	0.002

(continued)

Table 3.3 (continued)

Objective: Communicate (Weight of objective—Wife: 0.023)[f]

	MEH	SEH	BRH	OH	Eigenvector	Adjusted for power
BRH	0.25	3	1	4	0.236	0.005
OH	0.17	2	0.25	1	0.096	0.002

[a] $\lambda_{\max} = 6.499$, C.R. $= 0.08$
[b] $\lambda_{\max} = 5.286$, C.R. $= 0.07$
[c] $\lambda_{\max} = 5.398$, C.R. $= 0.09$
[d] $\lambda_{\max} = 4.205$, C.R. $= 0.08$
[e] $\lambda_{\max} = 6.309$, C.R. $= 0.05$
[f] $\lambda_{\max} = 4.220$, C.R. $= 0.08$

example, a very large living room and very small bedrooms or dining room would probably be considered to be misproportioned.

As an illustration we take the "Rest" objective which is allotted 433 sq. ft. Three types of spaces or rooms are associated with it. They and their comparisons according to relative contribution to "Rest" are shown in Tables 3.7, 3.8 and 3.9. The priorities and resulting proportion of the total area are given by:

	Architectural space	Objective's area	Weight	Area allocated to space (Sq. Ft.)
MB	Master bedroom	433	0.664	288
B-2	Bedroom 2	433	0.139	60.3
SR	Study room	433	0.197	85.3

Our goal now is to let both H and W determine the shape of different "Rest" areas, check for optimum size, and revise inconsistencies such as the one above, where B-2 should presumably have a higher weight than the SR. For each objective, we proceed according to the priority of the spaces within it by selecting the higher one, then the next higher and so on.

The first pairwise comparison was done on the Master Bedroom (see Table 3.10), given that this space is the most important with respect to the "Rest" objective. The dimensions developed through prioritization were 14′ by 20′ yielding 280 sq. ft. (less than the 288 sq. ft. allotted to this space). We must show how this is done. In the following pairwise comparisons, we assume that the parties had previously determined a set of dimensions to be ranked. To determine this set, H and W could use, as a reference point, their experience with currently known and used spaces, whose dimensions could accurately be measured. They could then make judgments accordingly. For example, suppose that H and W presently use a Master Bedroom whose dimensions are 14′ by 14′. Moreover, let us suppose that they feel comfortable with a width of 14′ but not with a 14′ length. They would then vary the length to make the comparisons as shown in Table 3.10.

It is clear that their preferred dimensions may not fit harmoniously with the total area for each objective. In this case adjustments must be made to produce a good

Table 3.4 Husband's priority of architectural spaces

Objective: Rest (Weight of objective—Husband: 0.096)[a]

	MB	B-2	LR	SR	MR	FR	Eigenvector	Adjusted for power
MB	1	3	0.33	0.25	0.25	1	0.084	0.008
B-2	0.33	1	0.25	0.20	0.20	0.25	0.041	0.004
LR	3	4	1	2	2	1	0.274	0.026
SR	4	5	0.50	1	1	3	0.238	0.023
MR	4	5	0.50	1	1	3	0.238	0.023
FR	1	4	1	0.33	0.33	1	0.125	0.012

Objective: Eat (Weight of objective—Husband: 0.068)[b]

	DR	FR	KIT	CP	G	Eigenvector	Adjusted for power
DR	1	1	5	1	1	0.250	0.017
FR	1	1	4	2	2	0.309	0.021
KIT	0.20	0.25	1	0.33	0.50	0.069	0.005
CP	1	0.50	3	1	1	0.193	0.013
G	1	0.50	2	1	1	0.179	0.012

Objective: Entertainment (Weight of objective—Husband: 0.260)[c]

	LR	FR	MR	LB	B	Eigenvector	Adjusted for power
LR	1	5	0.33	0.33	2	0.184	0.031
FR	0.20	1	0.50	0.33	1	0.087	0.015
MR	3	2	1	1	4	0.312	0.053
LB	3	3	1	1	5	0.342	0.058
B	0.50	1	0.25	0.20	1	0.074	0.013

Objective: Clean (Weight of objective—Husband: 0.019)[d]

	BTR1	BTR2	PWR	L	Eigenvector	Adjusted for power
BTR1	1	5	6	7	0.645	0.012
BTR2	0.20	1	2	4	0.193	0.004
PWR	0.17	0.50	1	1	0.089	0.002
L	0.14	0.25	1	1	0.073	0.001

Objective: Store (Weight of objective—Husband: 0.017)[e]

	MBCL	B2CL	P	CCL	UCL	WHCL	Eigenvector	Adjusted for power
MBCL	1	3	4	5	3	2	0.368	0.006
B2CL	0.33	1	3	3	2	1	0.186	0.003
P	0.25	0.33	1	2	0.50	0.33	0.075	0.001
CCL	0.20	0.33	0.50	1	0.33	0.25	0.051	0.001
UCL	0.33	0.50	2	0.33	1	1	0.137	0.002
WHCL	0.50	0.1	0.33	0.25	1	1	0.183	0.003

Objective: Communicate (Weight of objective—Husband: 0.017)[f]

	MEH	SEH	BRH	OH	Eigenvector	Adjusted for power
MEH	1	5	4	6	0.591	0.010
SEH	0.20	1	0.33	0.50	0.076	0.001

(continued)

Table 3.4 (continued)

Objective: Communicate (Weight of objective—Husband: 0.017)[f]						
	MEH	SEH	BRH	OH	Eigenvector	Adjusted for power
BRH	0.25	3	1	4	0.236	0.004
OH	0.17	2	0.25	1	0.096	0.002

[a] $\lambda_{max} = 6.440$, C.R. = 0.07
[b] $\lambda_{max} = 5.098$, C.R. = 0.02
[c] $\lambda_{max} = 5.373$, C.R. = 0.09
[d] $\lambda_{max} = 4.119$, C.R. = 0.05
[e] $\lambda_{max} = 6.141$, C.R. = 0.02
[f] $\lambda_{max} = 4.220$, C.R. = 0.08

Table 3.5 H & W combined priorities of architectural spaces

Objective	Architectural space	Weight
E	LR Living room (from R & E)	0.195
	FR Family room (from R, M & E)	0.147
	MR Music room (from R & E)	0.105
	LB Library	0.075
	B Bar	0.033
M	DR Dining room	0.082
	KIT Kitchen	0.010
	CP Covered patio	0.028
R	MB Master bedroom	0.060
	B-2 Bedroom 2	0.080
	SR Study room	0.030
K	BTR1 Bathroom 1	0.047
	BTR2 Bathroom 2	0.017
	PWR Powder room	0.008
	L Laundry room	0.005
S	MBCL Master bedroom closet	0.015
	B2CL Bedroom 2 closet	0.009
	P Pantry	0.004
	CCL Coat closet	0.002
	UCL Utility closet	0.006
	WHCL Water heater closet	0.004
C	MEH Main entrance hall	0.023
	SEH Secondary entrance hall	0.003
	BRH Bedroom hall closet	0.009
	OH Other halls	0.004

Table 3.6 Allocation of areas

Total area to allocate	2000 Sq. Ft.					
Objective	R	M	E	K	S	C
Strength of objective	0.22	0.19	0.43	0.08	0.04	0.04
Area per objective	433.7	389.2	861.0	156.4	80.0	80.0

Table 3.7 Wife's preferences

Objective: Rest (Power of wife: 0.613)[a]

	MB	BR-2	SR	Eigenvector	Adjusted for power
MB	1	5	4	0.683	0.419
B-2	0.20	1	0.50	0.117	0.072
SR	0.25	2	1	0.200	0.123

Objective: Eating (Power of wife: 0.613)[b]

	DR	FR	KIT	CP	Eigenvector	Adjusted for power
DR	1	6	4	6	0.602	0.369
FR	0.17	1	0.33	3	0.111	0.068
KIT	0.25	3	1	4	0.139	0.139
CP	0.17	0.33	0.25	1	0.060	0.037

Objective: Entertainment (Power of wife: 0.613)[c]

	LR	FR	MR	LB	B	Eigenvector	Adjusted for power
LR	1	4	5	4	9	0.522	0.320
FR	0.25	1	2	1	7	0.174	0.107
MR	0.20	0.50	1	0.50	4	0.098	0.060
LB	0.25	1	2	1	7	0.174	0.107
B	0.11	0.14	0.25	0.14	1	0.032	0.020

Objective: Cleaning (Power of wife: 0.613)[d]

	BTR1	BTR2	PWR	L	Eigenvector	Adjusted for power
BTR1	1	4	6	4	0.570	0.350
BTR2	0.25	1	5	3	0.249	0.153
PWR	0.17	0.20	1	0.33	0.058	0.035
L	0.25	0.33	3	1	0.124	0.076

Objective: Store (Power of wife: 0.613)[e]

	MBCL	B2CL	P	CCL	UCL	WHCL	Eigenvector	Adjusted for power
MBCL	1	1	3	3	3	3	0.314	0.193
B2CL	1	1	2	2	2	2	0.240	0.147
P	0.33	0.50	1	1	1	1	0.111	0.068
CCL	0.33	0.50	1	1	1	1	0.111	0.068
UCL	0.33	0.50	1	1	1	1	0.111	0.068
WHCL	0.33	0.50	1	1	1	1	0.111	0.068

Objective: Communicate (Power of wife: 0.613)[f]

	MEH	SEH	BRH	OH	Eigenvector	Adjusted for power
MEH	1	4	0.33	0.20	0.121	0.074
SEH	0.25	1	0.14	0.13	0.044	0.027
BRH	3	7	1	0.33	0.272	0.167
OH	5	8	3	1	0.563	0.345

[a] $\lambda_{\max} = 3.025$, C.R. = 0.02
[b] $\lambda_{\max} = 4.211$, C.R. = 0.03
[c] $\lambda_{\max} = 5.152$, C.R. = 0.04
[d] $\lambda_{\max} = 4.223$, C.R. = 0.08
[e] $\lambda_{\max} = 6.018$, C.R. = 0.003
[f] $\lambda_{\max} = 4.153$, C.R. = 0.06

fit and by reducing or increasing the area allotted to that space. They would then examine whether this allocation is compatible with the priorities of the next space within the objective and the availability of remaining space to allocate to it. For example, MB is $14' \times 20'$ and B-2 is $14' \times 14'$, exceeding the area allotted to R (i.e., 433 sq. ft.). Thus SR could not be included. Later we also make adjustments in the areas allotted to the objectives, to remedy such violations. For example, this can be achieved in a second iteration, where the parties H and W change their preferences to a MB of $16' \times 16'$ which yields a total area of 256 sq. ft., and a B-2 of $14' \times 14'$ which when combined with the MB yield a total area of 424 sq. ft. assigned to the R objectives. This leaves 9 sq. ft. (433 sq. ft.—424 sq. ft.) as a residual area in the R objective.

This process can be continued for each of the remaining objectives, until a final list containing the dimensions of all spaces is achieved, as shown in Table 3.11. The last column of this table gives the surplus (or deficit) so far produced for each objective. The total area must be no more than 2000 sq. ft. This is attained by adjusting the dimensions of some spaces and by revising the priorities when it is clear that a serious judgment error has been committed and that the comparison made is unacceptable to each of the parties. People usually start out with high aspirations and end up making compromises.

Some of the inconsistencies are a result of disagreements between the parties as to what should be valued most. The comparisons are sometimes unrealistic and are adjusted in terms of what is needed apart from high ideals for variety. In the final analysis, the dimensions of each of the spaces are slightly adjusted to absorb a deficit and to yield a surplus to meet the overall constraint of space availability.

3.5 Contiguity of Architectural Spaces

To determine the location and contiguity of the architectural spaces, we first set down criteria for location. We note that the front view of a house usually faces the street and may be separated from it by a garden. The other three sides separate the house from neighbors with spaces of varying size, which may be used for different purposes, e.g., driveway, garden or the like. For the house under consideration, the dimensions are shown in Fig. 3.1, where the surrounding space is an open grassy area with a tree on the right hand side of the house. Note that the construction site must fall within the 4000 square foot rectangle in Fig. 3.1. Our task is to indicate the location of the objectives and then the spaces within this area.

Table 3.8 Husband's Preferences

Objective: Rest (Weight of objective—Wife: 0.121)[a]

	MB	B-2	LR	SR	MR	FR	Eigenvector	Adjusted for power
MB	1	3	6	5	5	7	0.428	0.052
B-2	0.33	1	7	8	8	6	0.337	0.041
LR	0.17	0.14	1	2	2	1	0.072	0.009
SR	0.20	0.13	0.50	1	1	3	0.065	0.008
MR	0.20	0.13	0.50	1	1	1	0.050	0.006
FR	0.14	0.17	1	0.33	1	1	0.048	0.006

Objective: Eating (Power of husband: 0.387)[b]

	DR	FR	KIT	CP	Eigenvector	Adjusted for power
DR	1	3	4	5	0.549	0.212
FR	0.33	1	1	3	0.193	0.075
KIT	0.25	1	1	3	0.182	0.070
CP	0.25	0.33	0.33	1	0.076	0.030

Objective: Entertainment (Power of husband: 0.387)[c]

	LR	FR	MR	LB	B	Eigenvector	Adjusted for power
LR	1	4	5	4	9	0.522	0.202
FR	0.25	1	2	1	7	0.174	0.067
MR	0.20	0.50	1	0.50	4	0.098	0.038
LB	0.25	1	2	1	7	0.174	0.067
B	0.11	0.14	0.25	0.14	1	0.032	0.012

Objective: Cleaning (Power of husband: 0.387)[d]

	BTR1	BTR2	PWR	L	Eigenvector	Adjusted for power
BTR1	1	4	6	4	0.570	0.220
BTR2	0.25	1	5	3	0.249	0.096
PWR	0.17	0.20	1	0.33	0.058	0.022
L	0.25	0.33	3	1	0.124	0.124

Objective: Store (Power of husband: 0.387)[e]

	MBCL	B2CL	P	CCL	UCL	WHCL	Eigenvector	Adjusted for power
MBCL	1	1	3	4	4	3	0.340	0.131
B2CL	1	1	2	2	2	2	0.236	0.091
P	0.33	0.50	1	1	1	1	0.108	0.042
CCL	0.25	0.50	1	1	1	1	0.104	0.040
UCL	0.25	0.50	1	1	1	1	0.104	0.040
WHCL	0.33	0.50	1	1	1	1	0.108	0.042

Objective: Communicate (Power of husband: 0.387)[f]

	MEH	SEH	BRH	OH	Eigenvector	Adjusted for power
MEH	1	4	0.33	0.20	0.121	0.047
SEH	0.25	1	0.14	0.13	0.044	0.017
BRH	3	7	1	0.33	0.272	0.105

(continued)

Table 3.8 (continued)

Objective: Communicate (Power of husband: 0.387)[f]						
	MEH	SEH	BRH	OH	Eigenvector	Adjusted for power
OH	5	8	3	1	0.563	0.218

[a] $\lambda_{max} = 3.009$, C.R. = 0.009
[b] $\lambda_{max} = 4.076$, C.R. = 0.03
[c] $\lambda_{max} = 5.152$, C.R. = 0.03
[d] $\lambda_{max} = 4.223$, C.R. = 0.08
[e] $\lambda_{max} = 6.046$, C.R. = 0.007
[f] $\lambda_{max} = 4.153$, C.R. = 0.06

Table 3.9 Allocation of areas to architectural spaces

Objective	Area of objective (sq. ft.)	Architectural space	Party's preferences		Combined weight	Area allocated
			W	H		
R	433.7	MB	0.419	0.245	0.664	288.0
		B-2	0.072	0.067	0.139	60.3
		SR	0.123	0.074	0.197	85.3
M	389.2	DR	0.369	0.212	0.582	226.4
		FR	0.068	0.075	0.143	55.6
		KIT	0.139	0.070	0.209	81.3
		CP	0.037	0.030	0.067	25.9
E	861.0	LR	0.320	0.202	0.522	449.6
		FR	0.107	0.067	0.174	149.9
		MR	0.060	0.038	0.098	84.1
		LB	0.107	0.067	0.174	149.9
		B	0.020	0.012	0.032	27.4
K	156.4	BTR1	0.350	0.220	0.570	89.1
		BTR2	0.153	0.096	0.249	38.9
		PWR	0.035	0.022	0.058	9.0
		L	0.076	0.048	0.124	19.3
S	80.0	MBCL	0.193	0.131	0.324	25.94
		B2CL	0.147	0.091	0.238	19.07
		P	0.068	0.042	0.110	8.82
		CCL	0.068	0.040	0.108	8.67
		UCL	0.068	0.040	0.108	8.67
		WHCL	0.068	0.042	0.110	8.82
C	80.0	MEH	0.074	0.047	0.121	9.64
		SEH	0.027	0.017	0.044	3.53
		BRH	0.167	0.105	0.272	21.79
		OH	0.345	0.218	0.563	45.01

Table 3.10 Dimensions of architectural space parties: H and W Objective: Rest

Master bedroom[a]

Dimensions	Area	14 × 14	14 × 16	16 × 16	14 × 20	Eigenvector
14 × 14	196	1	0.33	0.20	0.17	0.061
14 × 16	224	3	1	0.33	0.20	0.124
16 × 16	256	5	3	1	0.50	0.302
14 × 20	280	6	5	2	1	0.514

Bedroom 2[b]

Dimensions	Area	12 × 10	12 × 12	12 × 14	12 × 16	14 × 14	Eigenvector
12 × 10	120	1	0.33	0.25	0.20	0.17	0.045
12 × 12	144	3	1	0.33	0.25	0.20	0.080
12 × 14	168	4	3	1	0.33	0.33	0.154
12 × 16	192	5	4	3	1	0.33	0.269
14 × 14	196	6	5	3	3	1	0.451

[a] $\lambda_{max} = 4.094$ C.R. $= 0.04$
[b] $\lambda_{max} = 5.300$ C.R. $= 0.07$

Table 3.11 Dimensions of architectural spaces

Architectural space	Revised weight	Area	Dimensions	Surplus area
Master bedroom (MB)	0.590	256	16′ × 16′	9
Bedroom 2 (B-2)	0.387	138	2′ × 14′	
Dining room (DR)	0.576	224	4′ × 16′	5
Kitchen (KIT)	0.411	160	0′ × 16′	
Living room (LR)	0.558	480	0′ × 24′	37
Family room (FR)	0.260	224	4′ × 16′	
Library (LB)	0.139	120	0′ × 12′	
Bathroom 1 (BTR1)	0.518	81	9′ × 9′	(9)
Bathroom 2 (BTR2)	0.230	36	9′ × 4′	
Powder room (PWR)	0.102	16	4′ × 4′	
Laundry room (L)	0.205	32	8′ × 4′	
Master bedroom closet (MBCL)	0.375	30	10′ × 3′	(1)
Bedroom 2 closet (B-2CL)	0.263	21	7′ × 3′	
Pantry (P)	0.113	9	3′ × 3′	
Coat closet (CCL)	0.075	6	3′ × 2′	
Utility closet (UCL)	0.075	6	3′ × 2′	
Water heater closet (WHCL)	0.112	9	3′ × 3′	
Main entrance hall (MEH)	0.375	30	5′ × 6′	(24)
Secondary entrance hall (SEH)	0.250	20	4′ × 5′	
Bedroom hall (BRH)	0.338	27	9′ × 3′	
Other halls (OH)	0.338	27	9′ × 3′	
Totals (sq. ft.)		1982		18

We do not insist that there should be straight rectangular walls surrounding the construction site. Thus, the contiguity of the rooms and hence the general layout of the house is our next task, and is the most difficult. We focus on the three highest priority objectives: E,R and M. They have 84.2% of the weight. We divide the priority of each by their total, so that the three sum to unity.

	Prior weight	Cumulative weight	Adjusted weight
E	0.430	0.647	0.511
R	0.217	0.000	0.258
M	0.195	0.842	0.231

Next we identify the location criteria used to determine the relative importance of the different locations in this single level house (see Fig. 3.3). They are: Front View (FV) (facing yard and street); Back View (BV) (facing yard); Left Side View (LV); and Right Side View (RV) (with a tree).

We then develop priorities for the relative importance of these locations with respect to the objectives E, R and M. The parties may perform the following types of pairwise comparisons shown in Table 3.12 below, which answer the following question: Which location is most desirable for E or R or M?

Graphically, these priorities are illustrated in Fig. 3.4. Now we turn our attention to locating the highest priority room, the Living Room, in the highest priority location for Entertainment needs, which is in the Front View. To accomplish this task, the building area is divided into quadrants of $4' \times 4'$ as shown in Fig. 3.5, and the Husband and Wife may jointly (or separately if desired) attempt to position LR. This prioritization process shows which quadrants are chosen for the Living Room. Table 3.13 shows these calculations.

As we observe from this pairwise comparison, quadrant $C_{6–10}H_{6–10}$ was selected for the LR. Therefore, we proceed to lay it out in the lot as shown in Fig. 3.6.

Next, the parties position the second highest priority space in the house, the FR. Because this space satisfies E needs, it would also have to be positioned towards the front part of the lot as previously determined. Table 3.14 shows the calculations for the FR.

The third highest priority space is the LB, which is also the last space we must place within the E objective. Following the same procedure explained above, the parties determine its position by pairwise comparisons, as shown in Table 3.15.

The fourth ranking space was the DR, which now satisfies M needs. The parties now use the right hand side of the construction site to position this particular space. The same procedure will be applied to the next space in ranking, which happens to be the Master Bedroom, but this space will be placed towards the back part of the lot since it satisfies R needs. The positioning of this space is shown in Table 3.16 below and in Fig. 3.6.

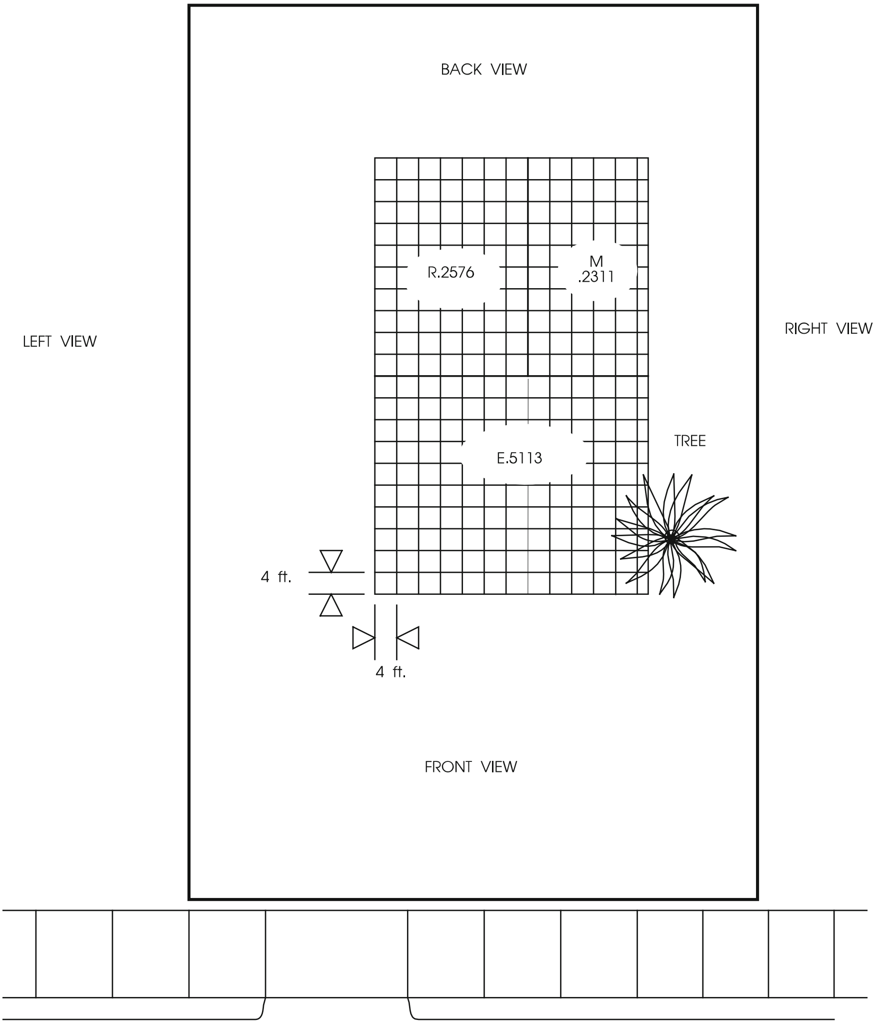

Fig. 3.3 Plot locations

This process can be continued in a systematic way, by positioning each remaining space, always working in the next highest priority space, until all the spaces have been placed. Figure 3.7 shows one of the possible solutions for the layout.

Having located the spaces of the three main objectives, the remaining spaces for storage, communication and cleaning are carefully placed within the remaining spaces. The closets are appropriately located in the rooms and halls, the dimension of which may be altered by reshaping the dimensions of adjacent rooms.

Table 3.12 Prioritization of Locations

Objective: Rest (Power of objective: 0.258) locations[a]

	FV	BV	LV	RV	Eigenvector	Adjusted for power
FV	1	0.25	0.33	0.50	0.095	0.025
BV	4	1	2	3	0.467	0.120
LV	3	0.50	1	2	0.277	0.071
RV	2	0.33	0.50	1	0.160	0.041

Objective: Entertainment (Power of objective: 0.511) locations[b]

	FV	BV	LV	RV	Eigenvector	Adjusted for power
FV	1	5	2	3	0.486	0.249
BV	0.20	1	0.33	0.33	0.080	0.041
LV	0.50	3	1	1	0.227	0.116
RV	0.33	3	1	1	0.207	0.106

Objective: Eat (Power of objective: 0.231) locations[c]

	FV	BV	LV	RV	Eigenvector	Adjusted for power
FV	1	2	2	0.33	0.220	0.051
BV	0.50	1	1	0.25	0.121	0.028
LV	0.50	1	1	0.25	0.121	0.028
RV	3	4	4	1	0.539	0.124

Objective:	FV	BV	LV	RV	Total
R	0.025	0.120	0.071	0.041	0.258
E	0.249	0.041	0.116	0.106	0.511
M	0.051	0.028	0.028	0.124	0.231

[a] $\lambda_{\max} = 4.031$, C.R. $= 0.01$
[b] $\lambda_{\max} = 4.034$, C.R. $= 0.01$
[c] $\lambda_{\max} = 4.021$, C.R. $= 0.008$

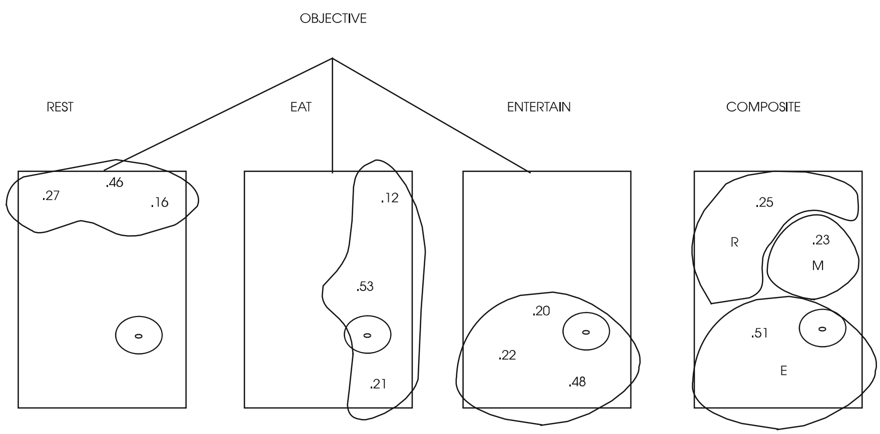

Fig. 3.4 Location of objectives

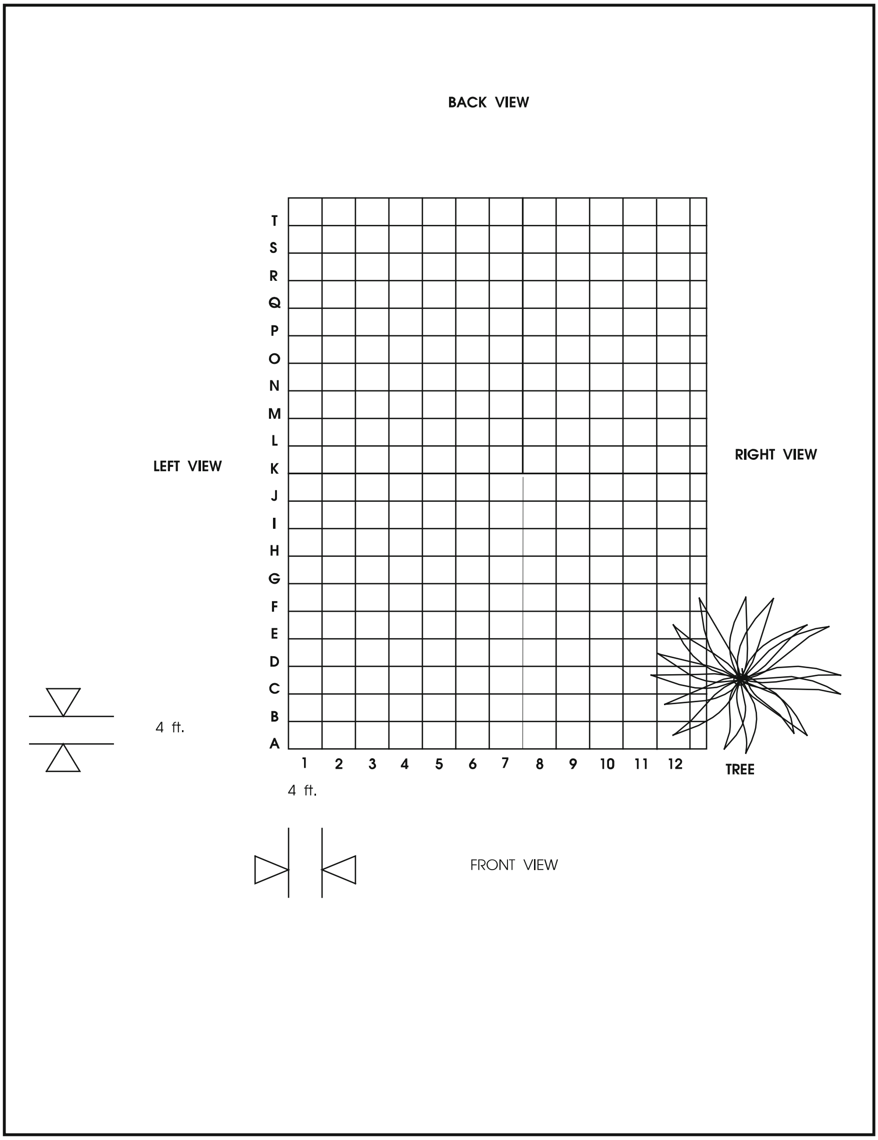

Fig. 3.5 $4' \times 4'$ Plot divisions

Alternative positions for bathrooms and closets, for example, can be similarly analyzed and located with respect to their bedrooms.

The readjustments involve iterations of the process to obtain a coherent architectural design. If the problem of locating rooms in a single level dwelling

Table 3.13 Positioning of the living room

	$A_{6-12}E_{6-12}$	$C_{6-10}H_{6-10}$	$A_{1-6}F_{1-6}$	$C_{1-5}H_{1-5}$	Eigenvector
$A_{6-12}E_{6-12}$	1	1/2	4	3	0.321
$C_{6-10}H_{6-10}$	2	1	4	3	0.455
$A_{1-6}F_{1-6}$	1/4	1/4	1	1/2	0.086
$C_{1-5}H_{1-5}$	1/3	1/3	2	1	0.139

$\lambda_{max} = 4.081$, C.R. = 0.03

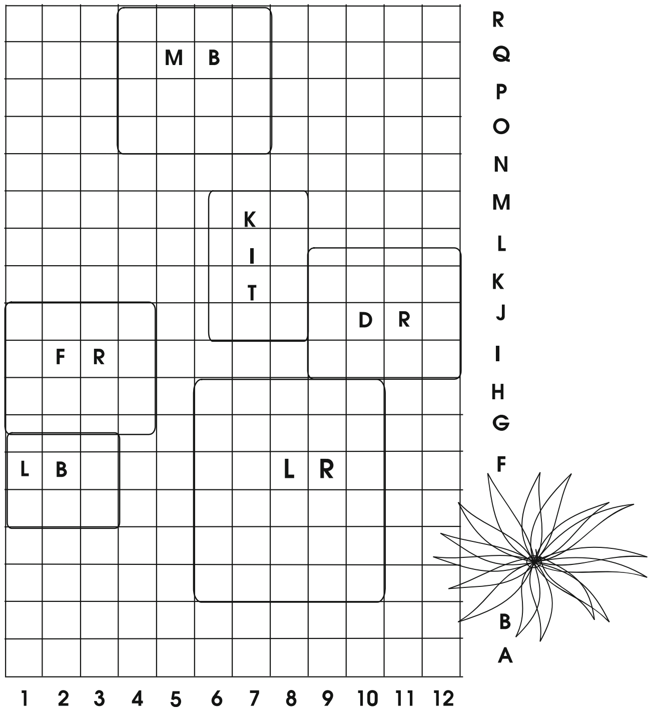

Fig. 3.6 Priority-based room locations

Table 3.14 Positioning of the family room

	$C_{1-4}F_{1-4}$	$E_{1-4}H_{1-4}$	$G_{1-4}J_{1-4}$	Eigenvector
$C_{1-4}F_{1-4}$	1	0.25	0.20	0.094
$E_{1-4}H_{1-4}$	4	1	0.33	0.280
$G_{1-4}J_{1-4}$	5	3	1	0.626

$\lambda_{max} = 3.086$, C.R. = 0.08

Table 3.15 Positioning of the library room

	$E_{1-3}G_{1-3}$	$D_{1-2}G_{1-2}$	$C_{1-3}E_{1-3}$	Eigenvector
$E_{1-3}G_{1-3}$	1	4	6	0.682
$D_{1-2}G_{1-2}$	0.25	1	4	0.236
$C_{1-3}E_{1-3}$	0.17	0.25	1	0.082

$\lambda_{max} = 3.108$, C.R. = 0.10

Table 3.16 MB and DR positioning

Positioning of the dining room[a]

	$I_{7-10}K_{7-10}$	$I_{9-12}K_{9-12}$	$I_{9-10}M_{9-10}$	Eigenvector
$I_{7-10}K_{7-10}$	1	0.20	0.25	0.090
$I_{9-12}K_{9-12}$	5	1	4	0.665
$I_{9-10}M_{9-10}$	4	0.25	1	0.245

Positioning of the master bedroom[b]

	$P_{1-4}S_{1-4}$	$O_{1-4}R_{1-4}$	$O_{4-7}R_{4-7}$	$K_{1-4}N_{1-4}$	Eigenvector
$P_{1-4}S_{1-4}$	1	0.33	0.25	0.50	0.093
$O_{1-4}R_{1-4}$	3	1	0.50	3	0.305
$O_{1-7}R_{1-7}$	4	2	1	3	0.459
$K_{1-4}N_{1-4}$	2	0.33	0.33	1	0.143

[a] $\lambda_{max} = 3.152$, C.R. = 0.15
[b] $\lambda_{max} = 4.081$, C.R. = 0.03

seems complicated, more than that of a two or more story house, it is even more complicated for a split-level house. The main reason for this is that one must not only locate rooms in the two levels, but must also match the levels at the boundary where they meet to obtain aesthetic, efficient and practical transition from one to the other. Split-level houses are known to provide the opportunity for greater efficiency and variety in using space that a two story house. Inclined ground is better suited to split-level housing than flat ground.

3.6 Conclusion

We have illustrated the use of a new method that can be used as an aid to formalize some of the intuitive aspects of architectural design. Through its use, the architect and the builder can enable owner participation (at the desired level) in the process.

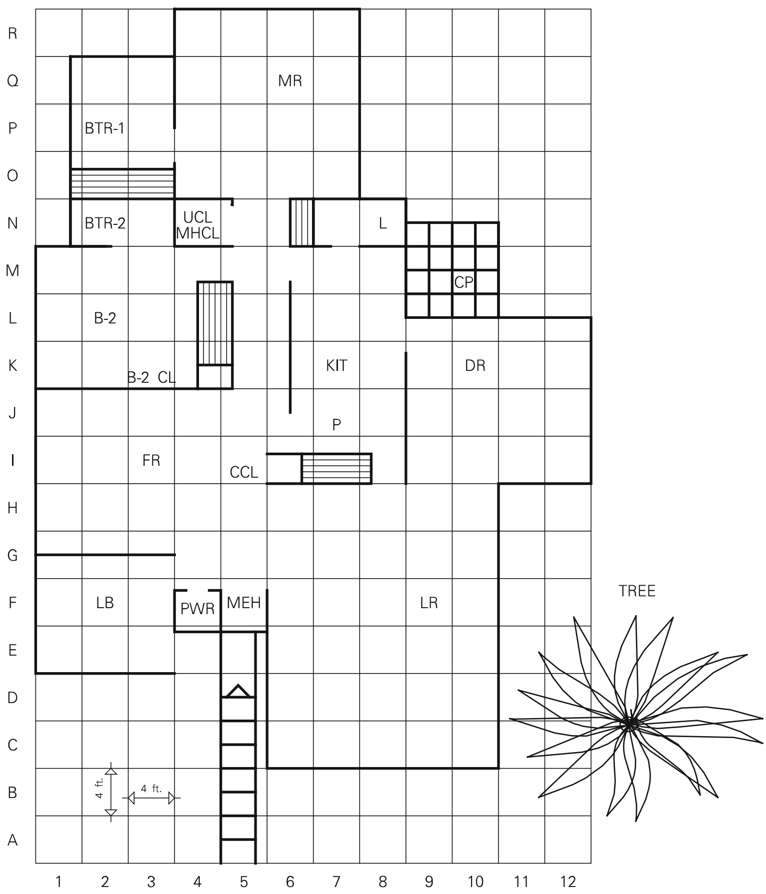

Fig. 3.7 The final layout—A possible solution

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Chapter 4
Why is the Principal Eigenvector Necessary?

4.1 Introduction

In the field of decision-making, the concept of priority is quintessential and how priorities are derived influences the choices one makes. Priorities should be unique and not one of many possibilities, they must also capture the dominance of the order expressed in the judgments of the pairwise comparison matrix. The idea of a priority vector has much less validity for an arbitrary positive reciprocal matrix $A = (a_{ij})$ than for a consistent and a near consistent matrix. A positive n by n matrix is reciprocal if $a_{ji} = 1/a_{ij}$. It is consistent if $a_{ij}a_{jk} = a_{ik}, i, j, k = 1, \ldots,$ n. From $a_{ij} = a_{ik}/a_{jk}$ we have $a_{ji} = a_{jk}/a_{ik} = a_{ij}^{-1}$ and a consistent matrix is reciprocal. A matrix is said to be near consistent if it is a small perturbation of a consistent matrix. The custom is to look for a vector $w = (w_1, \ldots, w_n)$ such that the matrix $W = (w_i/w_j)$ is "close" to $A = (a_{ij})$ by minimizing a metric. Metric closeness to the numerical values of the a_{ij} by itself says little about the numerical precision with which one element dominates another directly as in the matrix itself and indirectly through other elements as represented by the powers of the matrix. In this paper we show that with dominance order, the principal eigenvector, known to be unique to within a positive multiplicative constant (thus defining a ratio scale), and made unique through normalization, is the only plausible candidate for representing priorities derived from a positive reciprocal near consistent pairwise comparison matrix.

The Analytic Hierarchy Process (AHP) allows for inconsistency because in making judgments people are more likely to be cardinally inconsistent than cardinally consistent because they cannot estimate precisely measurement values even from a known scale and worse when they deal with intangibles (a is preferred to b twice and b to c three times, but a is preferred to c only five times) and ordinally intransitive (a is preferred to b and b to c but c is preferred to a). One reason for filling out an entire matrix is to improve the validity of the judgments in

T. L. Saaty and L. G. Vargas, *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*, International Series in Operations Research & Management Science 175,
DOI: 10.1007/978-1-4614-3597-6_4,

the real world. When we deal with tangibles, a pairwise comparison judgment matrix may be perfectly consistent but irrelevant and far off the mark of the true values. For several reasons a modicum of inconsistency may be considered as a good thing and forced consistency without knowledge of the precise values as an undesirable compulsion. If one insists on consistency, people would be required to be like robots, unable to change their minds with new evidence, and unable to look within for judgments that represent their thoughts, feelings and preferences.

The AHP also uses a principle of hierarchic composition to derive composite priorities of alternatives with respect to multiple criteria from their priorities with respect to each criterion. It consists of multiplying each priority of an alternative by the priority of its corresponding criterion and adding over all the criteria to obtain the overall priority of that alternative. This is perhaps the simplest way for composing priorities. The additive approach is also crucial in doing composition using the limiting powers of a priority rather than a judgment matrix when dependence and feedback are considered in decision-making. Different methods for deriving priorities within the same hierarchy can lead to different final values for the alternatives [6].

4.2 What is a Priority Vector?

Now we ask the question, what is priority or more generally what meaning should we attach to a priority vector of a set of alternatives? We can think of two meanings. The first is a numerical ranking of the alternatives that indicates an order of preference among them. The other is that the ordering should also reflect intensity or cardinal preference as indicated by the ratios of the numerical values and is thus unique to within a positive multiplicative constant (a similarity transformation). It is the latter that interests us here as it relates to the principle of hierarchic composition under a single criterion. Given the priorities of the alternatives and given the matrix of preferences for each alternative over every other alternative, what meaning do we attach to the vector obtained by weighting the preferences by the corresponding priorities of the alternatives and adding? It is another priority vector for the alternatives. We can use it again to derive another priority vector ad infinitum. Even then what is the limit priority and what is the real priority vector to be associated with the alternatives? It all comes down to this: What condition must a priority vector satisfy to remain invariant under the hierarchic composition principle? A priority vector must reproduce itself on a ratio scale because it is ratios that preserve the strength of preferences. Thus a necessary condition that the priority vector should satisfy is not only that it should belong to a ratio scale, which means that it should remain invariant under multiplication by a positive constant c, but also that it should be invariant under hierarchic composition for its own judgment matrix so that one does not keep getting new priority vectors from that matrix. In sum, a priority vector x must satisfy the relation $Ax = cx$, $c > 0$. We will show that as a result of the need for invariance to produce a unique priority vector, x must be the principal right eigenvector of A and c is its corresponding principal eigenvalue. Our problem for positive reciprocal matrices and their priorities is a special case of the following:

Theorem For a given positive matrix A, the only positive vector x and only positive constant c that satisfy $Ax = cx$, is a vector x that is a positive multiple of the Perron vector (principal eigenvector) of A, and the only such c is the Perron value (principal eigenvalue) of A.

Proof We know that the (right) Perron vector and Perron value satisfy our requirements. We also know that the algebraic multiplicity of the Perron value is one, and that there is a positive left eigenvector of A (call it z) corresponding to the Perron value. Suppose there is a positive vector y and a (necessarily positive) scalar d such that $Ay = dy$. If d and c are not equal, then by biorthogonality [2] y is orthogonal to z, which is impossible since both vectors are positive. If d and c are equal, then y and x are dependent since c has algebraic multiplicity one, and y is a positive multiple of x.

It is also true that if one starts with any priority vector and transforms it through multiplication by A any number of times, in the limit, the product converges to the Perron vector of A. Significantly and interestingly, for our purpose to derive priorities for a special type of positive matrices, the foregoing theorem can also be shown to hold for a class of positive reciprocal matrices that are consistent and near consistent without the use of the theorem of Perron. We know that the principal eigenvector is the priority vector of a consistent matrix. For such a matrix $a_{ij} = w_i/w_j$, and it follows from $Aw = nw$ that the vector $w = (w_1, \ldots, w_n)$ that is also the principal eigenvector of A is its priority vector with corresponding principal eigenvalue $c = n$. We can show by small and continuous perturbation [3, 8] of a consistent matrix A that the resulting near consistent matrix (see the next section), has its priority vector as its principal eigenvector obtained as a perturbation of the corresponding principal eigenvector of A. Thus if we assume that a judgment matrix is obtained as a small perturbation of an underlying consistent matrix constructed from a ratio scale $w = (w_1, \ldots, w_n)$, its priority vector coincides with its principal eigenvector obtained as a small perturbation of w. For the perturbation proof, which is fairly long and elaborate, see [5].

That would end our quest if we could also say what to do about a positive inconsistent matrix with large inconsistency. We need to improve its consistency to speak of its priority vector. Using the Perron vector and Perron root of such a matrix, we show that it can be transformed in steps to a near consistent matrix whose priority vector we now know is its principal eigenvector.

4.3 Some Observations on Positive Reciprocal Matrices and their Perturbation

We have for an n by n consistent matrix A: $A^k = n^{k-1} A$, $A = (w_i/w_j)$. A near consistent matrix is a small reciprocal (multiplicative) perturbation of a consistent matrix. It is given by the Hadamard product: $A = WoE$ where $W = (w_i/w_j)$ and $E \equiv (\varepsilon_{ij}), \varepsilon_{ji} = \varepsilon_{ij}^{-1}$. Small means ε_{ij} is close to one. Unlike an additive perturbation of the form $a_{ij} + \gamma_{ij}$, a reciprocal perturbation $a_{ij}\varepsilon_{ij}, \varepsilon_{ji} = \varepsilon_{ij}^{-1}$ is multiplicative. It can be transformed to an additive perturbation of a consistent matrix by writing:

$$\frac{w_i}{w_j} + \gamma_{ij} = \frac{w_i}{w_j}\varepsilon_{ij}, \quad \varepsilon_{ij} = 1 + \frac{w_j}{w_i}\gamma_{ij}, \quad \varepsilon_{ji} = \varepsilon_{ij}^{-1} = \frac{w_j}{w_i} + \gamma_{ji} = \frac{1}{1 + \frac{w_j}{w_i}\gamma_{ij}}.$$

Note that with a reciprocal perturbation we ensure that $\lambda_{\max} \geq n$ which helps determine the validity of w as a priority vector of a near consistent matrix. We have

$$\sum_{j=1}^{n} \varepsilon_{ij} = \sum\nolimits_j a_{ij} w_j / w_i = [Aw]_i / w_i = \lambda_{\max} w_i / w_i = \lambda_{\max}.$$

The computation

$$\begin{aligned} n\lambda_{\max} &= \sum_{i=1}^{n} \Big(\sum_{j=1}^{n} \varepsilon_{ij}\Big) = \sum_{i=1}^{n} \varepsilon_{ii} + \sum_{\substack{i,j=1 \\ i \neq j}}^{n} (\varepsilon_{ij} + \varepsilon_{ji}) \\ &= n + \sum_{\substack{i,j=1 \\ i \neq j}}^{n} (\varepsilon_{ij} + \varepsilon_{ij}^{-1}) \geq n + (n^2 - n)/2 = n^2 \end{aligned}$$

reveals that $\lambda_{\max} \geq n$. Moreover, since $x + 1/x \geq 2$ for all x > 0, with equality if and only if $x = 1$, we see that $\lambda_{\max} = n g_{\mathrm{ij}}$ if and only if all $\gamma_{\mathrm{ij}} = 1$, which is equivalent to having all $a_{ij} = w_i/w_j$. The foregoing arguments show that a positive reciprocal matrix A has $\lambda_{\max} \geq n$, with equality if and only if A is consistent.

4.4 The General Case: How to Transform a Positive Reciprocal Matrix to a Near Consistent Matrix

To improve the validity of the priority vector, we must transform a given reciprocal judgment matrix to a near consistent matrix. In practice, the judgments available to make the comparisons may not be sufficient to bring the matrix to near consistency. In that case we abandon making a decision based on the information we have, and must seek additional knowledge to modify the judgments.

The final question then is how to construct the γ perturbations in a general reciprocal matrix. A judgment matrix already has some built in consistency; it is not an arbitrary reciprocal matrix. Among others, inconsistency in a matrix may be due to an error such as putting a_{ji} instead of a_{ij} in the i,j position which if appropriately detected and changed the matrix may become near consistent or at least improve the consistency of A. Because the principal eigenvector is necessary for representing dominance (and priorities when near consistency is obtained), we must use an algorithm based on the eigenvector, whose existence is assured by

Table 4.1 A family's house buying pairwise comparison matrix for the criteria

	Size	Trans	Nbrhd	Age	Yard	Modern	Cond	Finance	w	v
Size	1	5	3	7	6	6	1/3	1/4	0.173	0.047
Trans	1/5	1	1/3	5	3	3	1/5	1/7	0.054	0.117
Nbrhd	1/3	3	1	6	3	4	6	1/5	0.188	0.052
Age	1/7	1/5	1/6	1	1/3	1/4	1/7	1/8	0.018	0.349
Yard	1/6	1/3	1/3	3	1	1/2	1/5	1/6	0.031	0.190
Modern	1/6	1/3	1/4	4	2	1	1/5	1/6	0.036	0.166
Cond	3	5	1/6	7	5	5	1	1/2	0.167	0.059
Finance	4	7	5	8	6	6	2	1	0.333	0.020

$8_{\max} = 9.669$
Consistency ratio (CR) = 0.17

Perron's theory for positive matrices, to improve the consistency of a reciprocal matrix until it is near consistent. Can we do that?

For a given positive reciprocal matrix $A = [a_{ij}]$ and a given pair of distinct indices $k > l$, define $A(t) = [a_{ij}(t)]$ by $a_{kl}(t) = a_{kl} + t$, $a_{lk}(t) = (a_{lk} + t)^{-1}$, and $a_{ij}(t) = a_{ij}$ for all $i > k$, $j > l$, so $A(0) = A$. Let $\lambda_{\max}(t)$ denote the Perron eigenvalue of $A(t)$ for all t in a neighborhood of $t = 0$ that is small enough to ensure that all entries of the reciprocal matrix $A(t)$ are positive there. Finally, let $v = [v_i]$ be the unique positive eigenvector of the positive matrix A^T that is normalized so that $v^T w = 1$. Then a classical perturbation formula [2, theorem 6.3.12] tells us that

$$\left.\frac{d\lambda_{\max}(t)}{dt}\right|_{t=0} = \frac{v^T A'(0) w}{v^T w} = v^T A'(0) w = v_k w_l - \frac{1}{a_{kl}^2} v_l w_k.$$

We conclude that

$$\frac{\partial \lambda_{\max}}{\partial a_{ij}} = v_i w_j - a_{ji}^2 v_j w_i \text{ for all } i,j = 1,\ldots,n.$$

Because we are operating within the set of positive reciprocal matrices, $\frac{\partial \lambda_{\max}}{\partial a_{ji}} = -\frac{\partial \lambda_{\max}}{\partial a_{ij}}$ for all i and j. Thus, to identify an entry of A whose adjustment within the class of reciprocal matrices would result in the largest rate of change in $\lambda_{\max}$ we should examine the n(n − 1)/2 values $\{v_i w_j - a_{ji}^2 v_j w_i\}, i > j$ and select (any) one of largest absolute value. This is the method proposed for positive reciprocal matrices by Harker [1].

To illustrate the methods discussed above, consider an example involving the prioritization of criteria used to buy a house for a family whose members cooperated to provide the judgments (Table 4.1).

Table 4.2 gives the array of partial derivatives for the matrix of criteria in Table 4.1.

The (4, 8) entry in Table 4.2 (in bold print) is largest in absolute value. Thus, the family could be asked to reconsider their judgment (4, 8) of Age versus Finance.

Table 4.2 Partial derivatives

	Size	Trans	Nbrhd	Age	Yard	Modern	Cond	Finance
Size	–	0.001721	0.007814	–0.00041	0.00054	0.000906	–0.08415	–0.03911
Trans	–	–	–0.00331	0.001291	0.002485	0.003249	–0.06321	–0.01336
Nbrhd	–	–	–	–0.00091	–0.00236	–5.7E-05	0.008376	–0.07561
Age	–	–	–	–	–0.01913	–0.03372	0.007638	**0.094293**
Yard	–	–	–	–	–	–0.01366	–0.01409	0.041309
Modern	–	–	–	–	–	–	–0.02599	0.029355
Cond	–	–	–	–	–	–	–	0.006487
Finance	–	–	–	–	–	–	–	–

Table 4.3 $\gamma_{ij} = a_{ij}\ w_j/w_i$

1.00000	1.55965	3.26120	0.70829	1.07648	1.25947	0.32138	0.48143
0.64117	1.00000	1.16165	1.62191	1.72551	2.01882	0.61818	0.88194
0.30664	0.86084	1.00000	0.55848	0.49513	0.77239	**5.32156**	0.35430
1.41185	0.61856	1.79056	1.00000	0.59104	0.51863	1.36123	2.37899

One needs to know how much to change a judgment to improve consistency, and we show that next. One can then repeat this process with the goal of bringing the C.R. within the desired range. If the indicated judgments cannot be changed fully according to one's understanding, they can be changed partially. Failing the attainment of a consistency level with justifiable judgments, one needs to learn more before proceeding with the decision.

Two other methods, presented here in order of increasing observed efficiency in practice, are conceptually different. They are based on the fact that

$$n\lambda_{\max} - n = \sum_{\substack{i,j=1 \\ i \neq j}}^{n} (\varepsilon_{ij} + \varepsilon_{ij}^{-1}).$$

This suggests that we examine the judgment for which γ_{ij} is farthest from one, that is, an entry a_{ij} for which $a_{ij}\ w_j/w_i$ is the largest, and see if this entry can reasonably be made smaller. We hope that such a change of a_{ij} also results in a new comparison matrix with that has a smaller Perron eigenvalue. To demonstrate how improving judgments works, take the house example matrix in Table 4.1. To identify an entry ripe for consideration, construct the matrix $\gamma_{ij} = a_{ij}\ w_j/w_i$ (Table 4.3). The largest value in Table 4.3 is 5.32156, which focuses attention on $a_{37} = 6$.

How does one determine the most consistent entry for the (3, 7) position? Harker has shown that when we compute the new eigenvector w after changing the (3, 7) entry, we want the new (3, 7) entry to be w3/w7 and the new (7, 3) to be w7/w3. On replacing a37 by w3/w7 and a73 by w7/w3 and multiplying by the vector w one obtains the same product as one would by replacing a37 and a73 by zeros and the two corresponding diagonal entries by two (see Table 4.4).

Table 4.4 Harker's method

	Size	Trans.	Nbrhd.	Age	Yard	Modern	Cond.	Finance	w
Size	1	1.7779	1.756208	0.774933	1.163989	1.418734	0.425449	0.494088	0.174
Trans.	0.562461	1	0.548777	1.556678	1.636746	1.994957	0.717895	0.794016	0.062
Nbrhd.	0.569408	1.822233	2	1.134652	0.994177	1.615679	0	0.675211	0.102
Age	1.290434	0.642394	0.881328	1	0.584131	0.533978	1.64704	2.23156	0.019
Yard	0.859115	0.610968	1.005857	1.711945	1	0.609428	1.315833	1.697915	0.034
Modern	0.704854	0.501264	0.618935	1.872735	1.640883	1	1.079564	1.39304	0.041
Cond.	2.35046	1.392962	0	0.60715	0.759975	0.9263	2	0.774223	0.223
Finance	2.02393	1.259421	1.481018	0.448117	0.588958	0.717855	1.291617	1	0.345

Table 4.5 Modified matrix in the a_{37} and a_{73} positions

	Size	Trans	Nbrhd	Age	Yard	Modern	Cond	Finance	*w*	*v*
Size	1	5	3	7	6	6	1/3	1/4	0.175	0.042
Trans	1/5	1	1/3	5	3	3	1/5	1/7	0.062	0.114
Nbrhd	1/3	3	1	6	3	4	1/2	1/5	0.103	0.063
Age	1/7	1/5	1/6	1	1/3	1/4	1/7	1/8	0.019	0.368
Yard	1/6	1/3	1/3	3	1	1/2	1/5	1/6	0.034	0.194
Modern	1/6	1/3	1/4	4	2	1	1/5	1/6	0.041	0.168
Cond	3	5	2	7	5	5	1	1/2	0.221	0.030
Finance	4	7	5	8	6	6	2	1	0.345	0.021

$8_{\max} = 8.811$
Consistency ratio (CR) = 0.083

We take the Perron vector of the latter matrix to be our w and use the now-known values of w3/w7 and w7/w3 to replace a37 and a73 in the original matrix. The family is now invited to change their judgment towards this new value of a37 as much as they can. Here the value was a37 = 0.102/0.223 = 1/2.18, approximated by 1/2 from the AHP integer valued scale and we hypothetically changed it to 1/2 to illustrate the procedure (see Table 4.5). If the family does not wish to change the original value of a 37, one considers the second most inconsistent judgment and repeats the process.

A refinement of this approach is due to W. Adams. One by one, each reciprocal pair a_{ij} and a_{ji} in the matrix is replaced by zero and the corresponding diagonal entries a_{ii} and a_{jj} are replaced by 2, the principal eigenvalue $\lambda_{\max}$ is then computed. The entry with the largest resulting $\lambda_{\max}$ is identified for change as described above. This method is in use in the Analytic Network Process (ANP) software program Superdecisions [4].

4.5 Conclusions

We have shown that if inconsistency is allowed in a positive reciprocal pairwise comparison matrix (which we have shown it must), the principal eigenvector is necessary for representing the priorities associated with that matrix, providing that the inconsistency is less than or equal to a desired value [7]. We also mentioned three ways and illustrated two of them, as to how to improve the consistency of judgments and transform an inconsistent matrix to a near consistent one.

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Chapter 5
Designing a Mousetrap

5.1 Introduction

This chapter illustrates the sequential use of hierarchies in the selection, design and marketing of a mouse trap. The project described in this chapter is not so much about building a better mousetrap as it is about a person's hope to reach a higher state by engulfing oneself in the project. Not a higher state in the classical sense that is indicative of a great mind expanding, but a state that helps a person to grow through doing, always reminding one that there are numerous ways to see a problem. By reminding the student to be open and sensitive to new ideas and new creative processes, the professor can foster positive growth. Emphasizing that you never reach a state where you are all that there is, and your ways are the best, can lead to a healthy respect for continued growth buttressed by a positive attitude, and a striving for a more fulfilling life.

A better mousetrap was not the goal of the assignment. To develop a person through the use of reasoning and agonizing can lead to a sense of accomplishment that comes only when the inputs come from within the person. The project has raised my self-esteem, while helping to humble me so that I can use my unique gifts while respecting the gifts of others in the healthiest of manners. A very fine line exists between self-confidence and arrogance when a person is elevated in this way, however, the sense of humility that comes from respecting the ideas of others can hold a check over the entire process.

5.2 Effectiveness Criteria

To design a new mousetrap, initial thinking centered around how today's mousetraps function and what makes them effective. Brainstorming revealed various methods of exterminating a rodent's life (Fig. 5.1).

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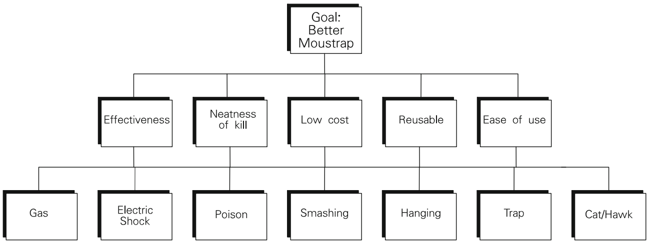

Fig. 5.1 Methods of extermination

Table 5.1 Priorities of alternative methods of extermination

Goal = Better mousetrap						
Criteria						
	Effectiveness	Neatness of kill	Low cost	Reusable	Ease of use	Composite priorities
Alternatives	0.564	0.220	0.137	0.039	0.039	
Gas	0.208	0.228	0.040	0.216	0.161	0.188
Electric shock	0.208	0.403	0.090	0.210	0.161	0.223
Poison	0.208	0.091	0.052	0.032	0.161	0.152
Smashing	0.208	0.164	0.141	0.210	0.161	0.187
Hanging	0.093	0.057	0.247	0.045	0.161	0.107
Trap	0.055	0.037	0.405	0.210	0.161	0.109
Cat/hawk	0.022	0.021	0.025	0.077	0.032	0.025

To evaluate the various methods of execution, criteria had to be identified for judging the effectiveness of the trap and the neatness of the kill to distinguish one method from another. Other criteria included were low cost, reusability and ease of use. The alternative methods to kill a mouse were electric shock, gas, poison, hanging, smashing and trapping. Based on the evaluation of the six criteria, it was determined that electric shock was the most desirable method (Table 5.1).

The next step was to determine where to aim the shock (Level 2 in Fig. 5.2). The results of the hierarchy (Table 5.2) led to the legs and feet being evaluated at 0.497, the head of the mouse coming in second at 0.216 and an inconsistency ratio of 0.077.

The findings from the second model led to the development of a third model (Level 3 in Fig. 5.2). In it the alternatives of the second model were used to evaluate various methods for delivering the electric shock. This third model, the optimal shock delivery system had, as its alternatives, a floating wire system, a wire griding system, a full chamber shock system using a side to side delivery wave of electricity and a polarized shock pattern which would run from end to end on the trap (Table 5.3).

Once the synthesis was completed it was clear that given the weights assigned to the criteria, a wire grid design would provide the best means of delivering the

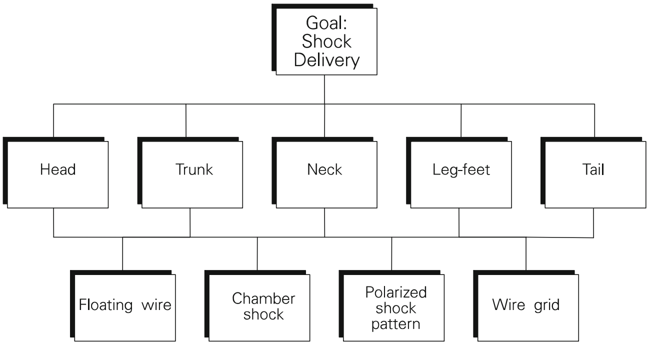

Fig. 5.2 Shock delivery methods

Table 5.2 Judgements and priorities with respect to goal for optimal shock delivery

	Head	Trunk	Neck	Leg-feet	Tail
Head		3.0	2.0	1/4	5.0
Trunk			1/2	1/5	4.0
Neck				1/4	4.0
Leg-feet					5.0
Tail					
0.216					
Head	XXXXXXXXXXXXXXX				
0.099					
Trunk	XXXXXXX				
0.142					
Neck	XXXXXXXXXX				
0.497					
Leg-feet	XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX				
0.047					
Tail	XXXXXX				

Table 5.3 Alternative methods for delivering the shock

Goal = Shock delivery						
Criteria						
	Head	Trunk	Neck	Leg/feet	Tail	Composite parts
Alternatives	0.216	0.099	0.142	0.497	0.047	
Floating wire	0.173	0.095	0.077	0.055	0.05	0.090
Chamber shock	0.377	0.594	0.294	0.148	0.408	0.274
Polarized shock	0.377	0.246	0.572	0.135	0.424	0.273
Pattern						
Wire grid	0.073	0.064	0.056	0.662	0.063	0.362

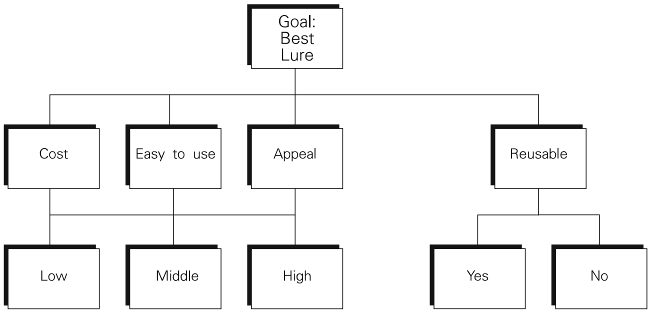

Fig. 5.3 Best lure

Table 5.4 Alternative lures

Goal = Best lure				
Criteria				
	Cost	Easy to use	Appeal	Reusable
Alternatives	0.062	0.126	0.594	0.218
Low	0.637	0.075	0.073	N/A
Middle	0.258	0.229	0.226	N/A
High	0.105	0.696	0.700	N/A
Yes	N/A	N/A	N/A	0.615
No	N/A	N/A	N/A	0.385

shock to the mouse's legs and feet (and even any other body parts). As can be seen from the first three models, the decisions made in each model drive those made in the subsequent model. With that in mind it was clear how to kill the rodent, what area should receive the shock and the optimal means to do it.

5.3 Attracting the Mouse

The next issue was how to attract the mouse to the trap. For this a fourth model was developed whose goal was to identify the best luring device (Fig. 5.3). Criteria included cost, with a set of sub-criteria; ease of use, also with sub-criteria; appeal (attracting power), with its own sub-criteria; and reusability. The alternative means of attracting a mouse were developed and evaluated under each set of criteria and sub-criteria.

The synthesis concluded that the alternatives of food scent and sex scent were within 0.001 of each other. For this reason it was decided to include both lures in the mousetrap. Combining food scent and sex scent would be much more powerful than attracting the rodent by means of any type of real food or dim lighting system (Table 5.4).

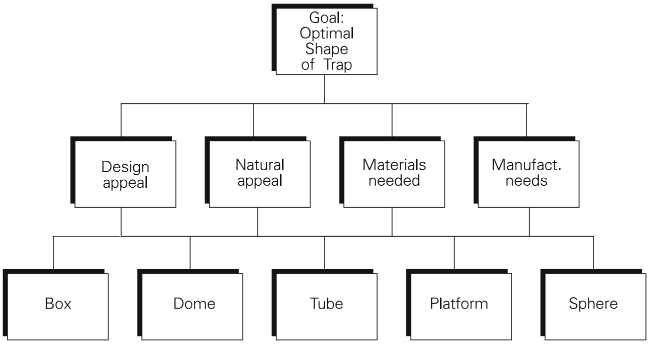

Fig. 5.4 Shape of the trap

Table 5.5 Alternative shapes

Criteria	Design appeal	Natural appeal	Materials needed	Manufact. needs	Composite priorities
Alternatives	0.226	0.590	0.092	0.092	
Box	0.158	0.156	0.166	0.230	0.164
Dome	0.205	0.143	0.084	0.107	0.148
Tube	0.465	0.534	0.425	0.215	0.479
Platform	0.075	0.067	0.259	0.364	0.114
Sphere	0.097	0.100	0.066	0.083	0.095

5.4 The Trap Shape

The fifth model was used to decide on the optimal shape of the trap given that the trap was to perform electrically (Fig. 5.4).

The alternatives generated included a sphere, a tube, a platform, a box and a dome. Each alternative was evaluated for its design appeal based on the presumed human need for an attractive trap. From the rodent's perspective, the trap needed natural appeal which focused on the mouse's curious nature. Other criteria were materials needed in construction and the various considerations about ease of manufacture (Table 5.5).

5.5 The Cost and Benefits of the Trap

Once the synthesis was completed, with an inconsistency ratio of 0.05, the obvious clear shape of choice was a tube design with a composite priority of 0.479. Up to this point it has been clear how each previous model drove the subsequent model's creation. Now, with all the elements in place, an idea born of the AHP could begin

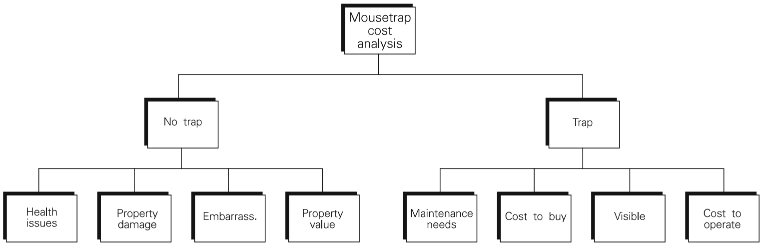

Fig. 5.5 Costs of the trap

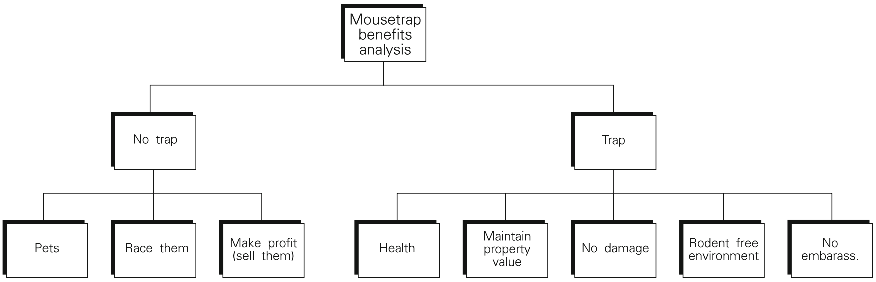

Fig. 5.6 Benefits of the trap

Table 5.6 Mousetrap cost analysis

	No trap 0.385		Trap 0.615
Health issues	0.606	Maintenance needs	0.495
Property damage	0.166	Cost to buy	0.128
Embarrassment	0.063	Visible	0.290
Property value	0.166	Cost to operate	0.088

to take form. Before entering the actual design phase, however, it was important to evaluate the costs and benefits of actual mousetraps. Two models were developed; one for the costs (Fig. 5.5) of the trap and the other for the benefits (Fig. 5.6). The mousetrap costs model looked at both using a trap and not using it. Under not using a trap further considerations included health issues, property damage, lower property value and the potential embarrassment of having rodents in the house. Sub-criteria under using a trap were the purchasing cost, the operating cost, trap maintenance time, the visibility of the trap in the house. Under the sub-criteria of not using the trap (i.e., health issue and property damage) were food damage, mouse's excrement in the house, the bite factor and damage considerations to clothes and furniture.

Table 5.7 Mousetrap benefits analysis

	No trap 0.417		Trap 0.583
Pets	0.504	Health	0.483
Race them	0.279	Maintain property value	0.228
Make profit	0.217	No damage	0.131
(Sell them)		Rodent free environment	0.106
		No embarrassment	0.053

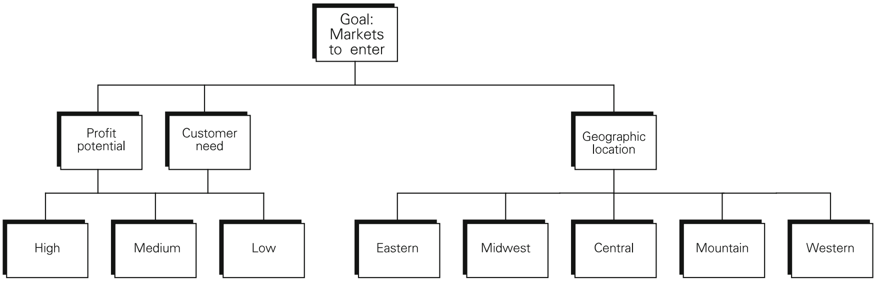

Fig. 5.7 Alternative regional markets

With the synthesis completed it became clear that the costs of having the trap outweighed those of not having the trap. Attention now focused on the benefits of using the trap given the findings of the last model (Table 5.6).

The benefits model, similar to the costs model, looked at both using and not using the mousetrap. Under using the trap, the issues included a clean home environment, maintaining current property value, no damage to food/clothes or property, a rodent free environment and no embarrassment due to the lack of a mouse. Considered under not using the trap were the opportunity to earn money by breeding and selling them, development of mouse races and the chance to obtain low cost pets. The mousetrap benefits model showed that the benefits of using a trap outweighed those of not using one and a subjective judgment followed that the benefits did outweigh the costs (Table 5.7).

5.6 A Marketing Model

At this point it seemed that only the trap design itself was left to be developed, but a question arose as to whether this trap, once developed, could prosper monetarily. Our concern now focussed on profits and on the development of a model (Figs. 5.7 and 5.8) that would assist in deciding which markets should be entered once the trap took physical form. Criteria included the trap's profit potential, customer need and geographic location. Both profit potential and customer need used sub-criteria

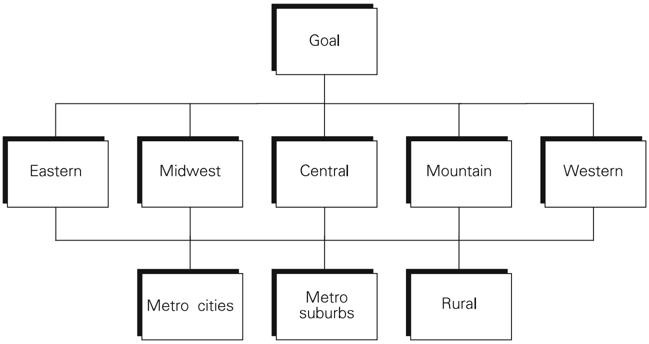

Fig. 5.8 Alternative marketing locations

Table 5.8 Priorities of alternative regional markets

Goal = Markets to enter

Criteria	Profit potential	Customer need	Geographic location
Alternatives	0.660	0.211	0.129
High	0.938	0.738	N/A
Medium	0.196	0.196	N/A
Low	0.065	0.065	N/A
Eastern	N/A	N/A	0.362
Midwest	N/A	N/A	0.251
Central	N/A	N/A	0.148
Mountain	N/A	N/A	0.100
Western	N/A	N/A	0.138

Table 5.9 Priorities of alternative marketing locations

	Eastern	Midwest	Central	Mountain	Western
Alternatives	0.302	0.251	0.148	0.100	0.138
Metro cities	0.249	0.249	0.249	0.249	0.249
Metro suburbs	0.594	0.594	0.594	0.594	0.594
Rural	0.157	0.157	0.157	0.157	0.157

of high, medium and low with greatest weight going to high. Geographic location had sub-criteria of sections of the country (i.e., Eastern, Midwest, Central, Mountain and Western). Under these were the alternatives of metro cities, metro suburbs and rural areas. Once the synthesis was completed the first choice of a market to enter was found to be metro suburbs at 0.549, followed by metro cities at 0.266 and rural at 0.185 (Tables 5.8 and 5.9).

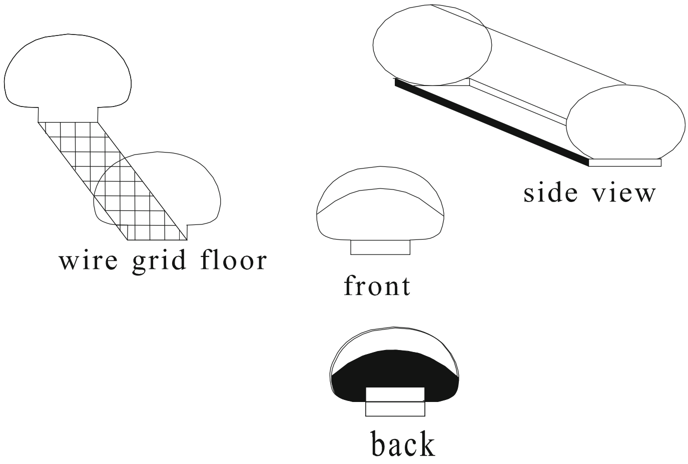

Fig. 5.9 Preliminary drawing of the trap

Fig. 5.10 Overview

5.7 The Design

With regard to the actual trap, some of the design questions included the shape of the entrance to the trap, how long should the trap be, where to place wire griding, how to make it reusable and a number of other questions. Figure 5.9 contains the preliminary drawings of the front and back of the trap and one complete sideview. Also, a picture of the front and back with the wire grid floor is included to aid in understanding the design.

Figures 5.10, 5.11, 5.12 and 5.13 contain the formal design plans. Figure 5.10 gives an overview of the trap. The 3 1/4″ section outlines the inner chamber while the 4 1/4″ section shows the outlays of the chamber. All solid lines depict the outer layer of steel and the inner dashed line depicts the thickness of the materials used. This convention is adhered to for all the following exhibits.

Figure 5.11 contains views of the front and rear ends. If the trap was "electrified" at all times, it was unlikely that a mouse would enter. A means of detecting entry was needed to send a signal to the delay mechanism housing assembly.

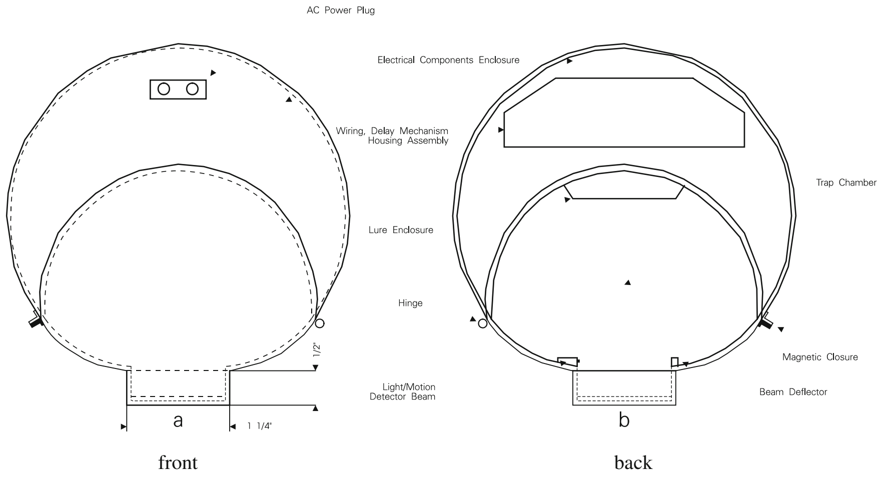

Fig. 5.11 End views

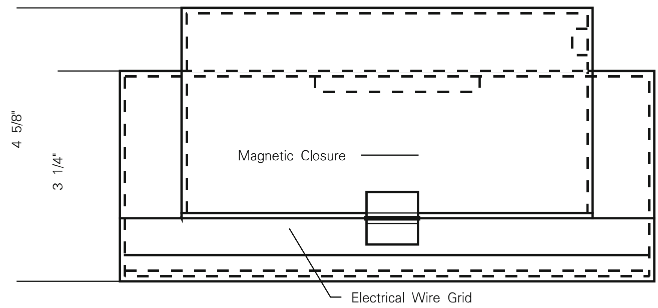

Fig. 5.12 Rear elevation

At 1.2 s after the beam is broken, the four corners of the wire griding receive an electrical charge of 110 V. The trap chamber is the section that the mouse enters while the electrical components enclosure opens to dispose of the dead rodent with a twist of the wrist. This is why a seven inch piano hinge, and the magnetic closure are included. Remember the first hierarchy.

Reusability and ease of use were indeed among the initial criteria. The lure was located on the top section of the trap chamber to make replacement easy and to force the mouse's weight downward on the wire grid as it pushed up to get toward the lure.

Figure 5.12 is the rear elevation, the view of the trap from its magnetic closure side.

Figure 5.13 contains two views, a front elevation and Section A–A.

The front elevation is the hinge side. The overall length of the complete trap is 9″ long while the section that opens is 7″ long. While observing the front

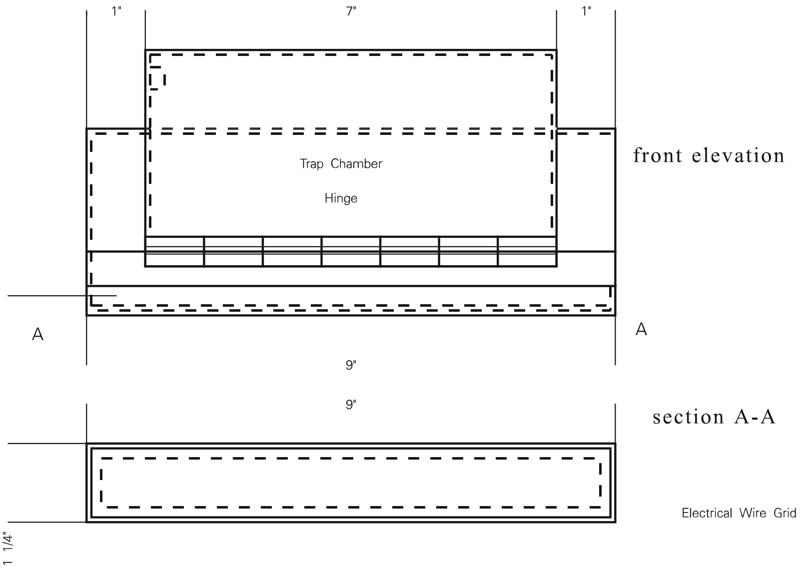

Fig. 5.13 Front and section elevations

Table 5.10 Master hierarchy

Goal						
1.000						
Type 0.430	SHK-Area 0.223	SHK-Del 0.123	OPT-Lure 0.073	OPT-Shap 0.060	CTS-Bene 0.050	Markets 0.041
-L-Cost 0.092	-Head 0.198	-FLT-Wire 0.056	-Cost 0.062	-DSGN-App 0.280	-Cost 0.500	PROFPOT 0.640
-Effecti 0.426	-Trunk 0.067	-Wiregrid 0.612	-Easy use 0.151	-NTL Appl 0.614	-Benefits 0.500	Cust-ND 0.288
-Neat 0.315	-Neck 0.132	-CHMB-SHK 0.160	-Appeal 0.635	-MAT-Need 0.053		Geo-Loc 0.073
-Reusable 0.095	-Leg-feet 0.552	-POLZ-SHK 0.173	-Reusable 0.151	-MFG-Need 0.053		
-Easy use 0.072	-Tail 0.051					

elevation, note the two downward pointing arrows labeled "A". This represents a cross-section of this area and a top down view can be seen in section A–A. This is the complete 9″ electrical wire grid that is located in the channel of the trap chamber.

It is important to note that this type of thinking and design can come only when you ask not only how it has been done, but how you might do it differently.

5.8 Conclusions

The AHP was used to model the stages of designing a new mouse trap. The model helps elucidate the thinking process. Without the beginning models as stepping stones, the later models would be meaningless separate entities with no tie to the overall goal of building a better mousetrap.

Table 5.10 contains an overall view of the reconstituted master hierarchy. Note that this exhibit displays only the first three levels of the total picture. To understand the complete model, it is useful to examine the previous tables and visualize where each component part fits.

This exercise (the overall model) demonstrates how decisions in one model lead to the creation of another model and affect choices made for each model thereafter. The cost/benefit analysis and the decision about what markets to enter were driven by the preceding models but not to the same extent that the first five models were. Although the master hierarchy model was created after the completion of the project, it serves to demonstrate the sequence of events followed and the relative importance of each with respect to those models they affected.

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Chapter 6
Designing the Best Catamaran

6.1 Introduction

This chapter illustrates use of the Analytic Hierarchy Process in the selection and design of a sailboat. How does one bring together one's ideas when designing a versatile sailing machine? Imagination plays an important role but is full of disconnected thoughts. The AHP was used to first choose the overall sailboat design, and then to select some fundamental hydrodynamic features of the newly designed boat.

There are four basic sailboat designs: sloop, ketch, catamaran and trimaran. The sloop has one hull and one mast. The ketch has one hull with one large mast located at the centerpoint of the yacht's deck, and a smaller mast (mizzenmast) that is usually located behind the helm (where the captain steers). Each vessel uses one mainsail and one jib (triangular shaped foresail), except for the ketch which also uses a mizzensail (mainsail on the mizzenmast).

A catamaran and a trimaran differ in only one major feature. The catamaran is made of two pontoons that are attached by a variety of spar configurations. Usually a tarp stretches between the two pontoons. The trimaran has three pontoons, with the center one being the main body of the vessel. These pontoons are usually connected by a reinforced fiberglass structure. Both the catamaran and the trimaran have one mast, that is located around the centerpoint.

By thoroughly evaluating each type of vessel, the AHP led to the development of a design comprising the best features of both the sloop and the catamaran. This new vessel design is called a Main-Hull-Mono-maran (MHM-maran). The MHM-maran broadly resembles a catamaran. It has two pontoons, but one is much larger than the other. The larger pontoon (major pontoon) is similar to a sloop in both size and appearance. The smaller pontoon (minor pontoon), is approximately 1/3 the length and 1/4 the width of the major pontoon. The minor pontoon is for added sailing performance while the major pontoon provides all living and storage facilities.

T. L. Saaty and L. G. Vargas, *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*, International Series in Operations Research & Management Science 175,
DOI: 10.1007/978-1-4614-3597-6_6,

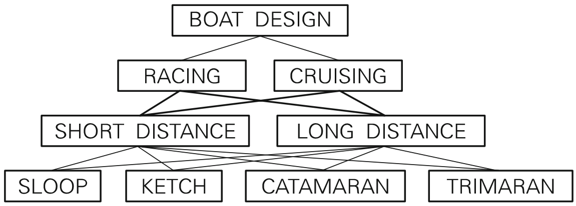

Fig. 6.1 Hierarchy of boat types

6.2 Basic Design

Four criteria were used (see Fig. 6.1) to evaluate the four alternative designs: catamaran, ketch, sloop and trimaran. With respect to sailing performance, both the sloop and the ketch have a greater ability to sail close to the wind (close-hauled position). But the marans are far lighter than their counterparts, thus they sail faster in most "points" of sailing. By points of sailing we mean the direction from which the wind is blowing: a run is with the wind blowing from behind, a reach is with the wind blowing from either side and close-to-the-wind (close-hauled) is with the wind blowing 30–35° off the bow.

The criteria were separated into two distinct categories: cruising and racing. With respect to personal design preferences, long-distance racing was the criterion that carried the greatest weight. Following it was short-distance racing, long-distance cruising and short-distance cruising, in that order. The goal was to design some sort of racing yacht.

Criteria	Weights
1. Short dist. racing	0.231
2. Long dist. racing	0.623
3. Short dist. cruising	0.052
4. Long dist. cruising	0.094

Until recently, the marans did not receive much respect when it came to structural integrity. They were not considered very seaworthy, and in storms the pontoons tended to break apart. But with the development of expensive and strong plastics, vast improvements have been made. Still, many sailors prefer the traditional structural strength of both the sloop and the ketch.

Evaluating each alternative with the above criteria revealed some interesting results. The catamaran, as almost every sailor knows, is superior to all other yachts when it comes to short-distance racing. It is very light and fast but it does not have adequate storage or living facilities, so it is not suitable for long-distance racing. Instead, the sloop was determined to be the best yacht for long-distance racing. It really did not matter which yacht was best for short or long-distance cruising, because neither of these criteria had significant weight to greatly affect the overall outcome. The overall weights of the alternatives are given by:

Alternatives	Weights
1. Sloop	0.379
2. Catamaran	0.348
3. Ketch	0.138
4. Trimaran	0.134

Notice how close the weights of both the sloop and the catamaran are. Up to this point, the results from each hierarchy were used without question, mainly because the final weights clearly marked which was the superior alternative. Before beginning this evaluation it was assumed that the conclusion would be the sloop. But this did not turn out to be the case. It was the catamaran. The catamaran ended up following the sloop by only 0.031. This led to an entirely new conclusion—the development of a sailboat that takes advantage of the distinct characteristics of both the sloop and the catamaran.

6.3 The Best Combination of Catamaran and Sloop: *A New Alternative*

Since a sloop consists of one large hull, and a catamaran consists of two pontoons, a yacht that combines both characteristics will have to be somewhere in between. Two options are possible—a yacht with one main hull and a single fixed pontoon or a yacht with a variable pontoon. This is where the concept of the Main Hull Mono-maran enters. It is a distinct yacht that has one large hull (main hull) that is shaped much like a sloop's hull. It also has an attached pontoon which provides the vessel with characteristics typically associated with a catamaran. When the sea is rough, one has the option to have the pontoon trail the vessel.

There are only two alternatives in this hierarchy, Yacht A and Yacht B. The only difference between them is that A has a fixed pontoon whereas B has a variable one which can move from the port to the starboard side and vice versa. There are three criteria: Agility (0.558), Stability (0.122) and Anchorability (0.320).

AGILITY is the ability of a design to quickly maneuver under sail. STABILITY is the ability to keep the yacht heeled as upright as possible. Finally, ANCHORABILITY refers to how easy it is to, or not to, anchor or dock the yacht. A fixed pontoon limits docking ability because the dock (slip) needs to be sufficiently wide to accommodate the vessel. The final weights for the two designs are given by:

Alternatives	Weights
Yacht B	0.696
Yacht A	0.304

Thus, in this hierarchy, Yacht B, the model with variable pontoon, is decidedly preferred.

Now that a basic yacht concept has been derived through the process provided by the AHP, the specifics of the MHM-maran, namely, the keel, the rudder, and the sails were designed.

6.4 The Keel

The keel is the most important hydrodynamic feature of any sailboat. A keel is responsible for a boat's stability and prevents it from sliding across the water on certain points of sailing (close-hauled & reach position). Once a keel is chosen, the rudder is relatively easy to design. As the hydrodynamics of the rudder are dependent upon those of the keel: there is a close relationship between keel and rudder.

Since the Australians introduced a winged keel in the 1983 America's Cup, there has been a tremendous amount of research in this area. Many of the keel test results are not available to the public, since it is mainly the very competitive yachting syndicates that perform and sponsor these activities.

When selecting a keel, performance and practicality were considered (see Fig. 6.2). The criteria were: mud, rock, sand and the degree of heel of the yacht. The mud, rock and sand elements were selected, because these are the substances that sailors most often hit when they go aground. A keel provides stability and many other performance factors, but in this case only the degree of heel (leaning to one side) was taken into consideration. The two criteria (performance and practicality) were considered equally important, and within practicality, the three substances the keel can come in contact with are also considered equally relevant.

Thus, we have:

Criteria	Weights
Heel	1/2
Mud	1/6
Rock	1/6
Sand	1/6

Keels are classified into three basic types—winged, torpedo and fin. A deep keel was not considered because such keels have been outdated and are poor performers. Generally speaking, a winged keel provides the least amount of heel because of the lift action that each wing creates as it glides through the water. The wings actually serve as a vertical stabilizer. As the yacht heels (leans on its side), the wings keep the boat a few more degrees upright. The benefit of such a feature is that it allows the vessel to catch as much wind as possible, while minimizing the amount spilled. However, a winged keel is unsuitable for the MHM-maran, because the minor pontoon will serve the same purpose. When the minor pontoon is correctly positioned on the leeward side of the vessel, it will

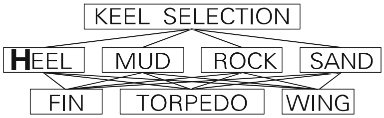

Fig. 6.2 Keel selection

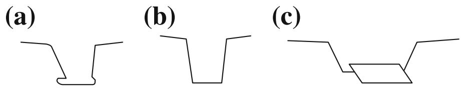

Fig. 6.3 Types of keels. **a** Torpedo keel. **b** Fin keel. **c** Medium oft-sweeping wing keel

effectively reduce the vessel's degree of heel. When evaluating the criteria, the wing was the least favored.

The torpedo keel outperforms the fin keel with the respect to heeling because the torpedo limits the amount of heel. The torpedo keel is given that name because it is a standard fin keel with a torpedo shaped bulb on the bottom (Fig. 6.3a). It is no longer a common type of keel, but at one time it was thought that having much of the lead weight at the base of the keel would act as a stabilizer. Some designers have combined the features of both the winged and torpedo keels.

The most common keel is the fin keel (Fig. 6.3b). It goes straight down deep and tends to draw much water. Variations of the fin keel exist, such as a shoal draft keel which draws less water, but is thicker and longer. The shoal draft keel was not considered because it is not a good hydrodynamic performer. The fin keel was favored and after placing it on the major pontoon, it was found to be an excellent choice. When sailing in a close-hauled or reach position, the fin keel would reduce the MHM-marans sliding effect across the water.

The winged keel presents a problem in mud (Fig. 6.3c). If one runs into mud, there is a good chance of getting stuck. The wings tend to anchor themselves into the mud, making it difficult to break away. The torpedo keel is no worse than the fin keel, but the bulb base can also stick into the mud.

Rocks are a problem for all keels. Sailing in shallow waters with a rocky bottom is hazardous. A winged keel does not fare well when it hits rock—structurally it can crack, or a wing can break off if the impact is sufficiently strong. A torpedo keel is better in rock than a winged keel but no better than a fin keel. A fin keel usually receives the least damage when its base hits rock. If the forward middle part of a keel is hit by rock, it could suffer chips and cracks.

When a boat hits sand, it goes "thump, thump" a sensation sometimes associated with engine problems. Fin and torpedo keels do about the same thing when hitting sand, causing the boat to skid across. With a winged keel, one needs to be concerned as to whether or not enough thump is due to one of the wings, which could break off. We have:

Alternatives	Weights
Fin	0.391
Torpedo	0.352
Wing	0.257

We determined that the fin keel is the best suited for our purposes. Earlier, we spoke of its hydrodynamic advantages. With respect to the environment, the fin keel is the least affected by different bottom surfaces. It is relatively easy to get out of the mud, and it is least damaged when coming into contact with hard surfaces.

6.5 The Rudder

There is a definite relationship between a keel and a rudder and once the keel type is selected, the rudder more or less falls into place. What had to be considered was the rudder work coefficient (CWR) and the angle of deflection. These became the criteria. There are three basic alternatives—an attached rudder, a skeg type and a spade rudder (see Fig. 6.4).

The attached rudder is connected to the keel with hinges (Fig. 6.5a). At one time, this type of rudder was widely used, especially when the yacht had a deep keel (a keel that began shortly after the bow and went all the way back to the aft). Neither deep keels nor attached rudders are in much use nowadays.

The skeg rudder is made in a variety of shapes and sizes (Fig. 6.5b). It is not attached to the keel. Rather, it is attached to a skeg that extends from the base of the hull. The theory behind such a design is that it is more streamlined and allows water to pass slightly faster by the rudder, thus making the rudder's movements more effective.

The spade rudder is the sailing industry's most commonly used rudder (Fig. 6.5c). It is attached to a rudder post which in turn is connected to the helm (steering wheel) by a pulley assembly mechanism. It is also made in a variety of shapes and sizes. Some go deep, but never deeper than the deepest point of the keel, while others tend to be less rectangular. This type tends to be the number one choice among yacht manufacturers today, mostly because it is easy to configure hydrodynamically with specific keel characteristics. Thus, it was not surprising that the spade rudder was the most favored. Spade rudders are commonly used in conjunction with fin keels.

Criteria	Weights	Alternatives	Weights
Rudder work coefficient	0.556	Spade	0.470
Angle of deflection	0.444	Skeg	0.319
		Attached	0.211

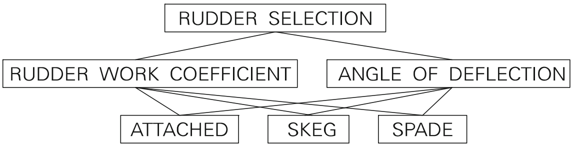

Fig. 6.4 Rudder selection

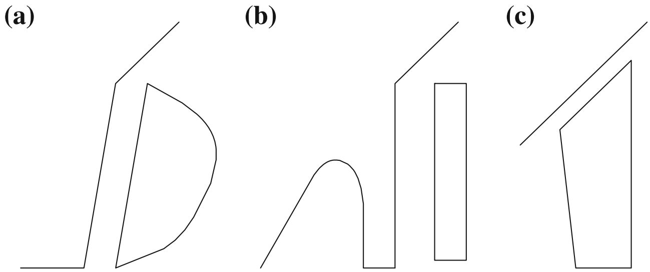

Fig. 6.5 Types of rudders **a** Deep keel with an attached rudder. **b** Skeg type rudder. **c** Spade rudder

6.6 The Overall Mhm-Maran Structure

So far we have selected the major underwater hydrodynamic features and the basic overall design (see Fig. 6.6). Now it is time to take a closer look. The big design problem is connecting the pontoons together. There are only two choices at this stage: one solid piece, or two poles (see Fig. 6.7).

Each choice had to be flexible enough, so that it would move with the pontoon to the other side of the vessel. A solid connection, that leaves no visible gap between both pontoons, raises the question of seaworthiness. Such a structure could get swamped by a wave and break. Also, a solid structure would weigh more than two poles, thus adding to the overall weight of the vessel.

By comparing both alternatives with respect to the criteria: the poles were most favored except on strength. Using poles is not only less expensive, but easier to design. On the main pontoon, a dual track assembly would follow the rear perimeter on which the ends of the poles would be attached. On the minor pontoon, two curved tracks would travel along the centerline where the poles would also connect (Fig. 6.8).

Criteria	Weights	Alternatives	Weights
Ease	0.637	Poles	0.528
Strength	0.258	Solid	0.472
Weight	0.105		

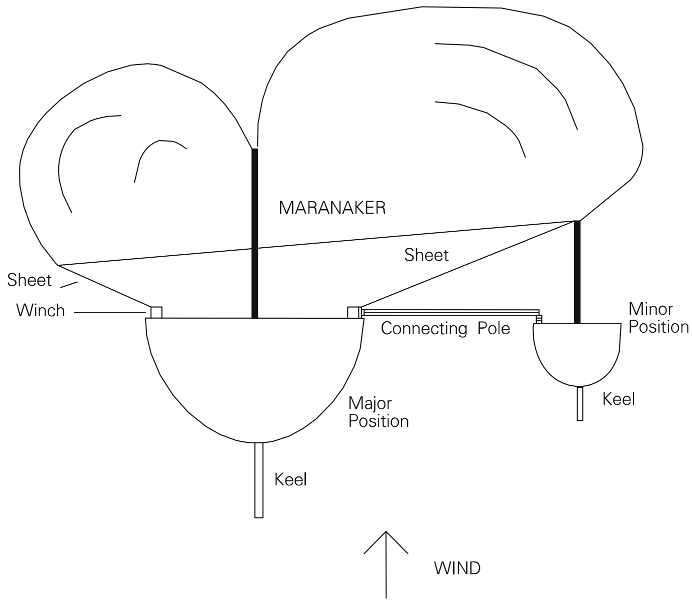

Fig. 6.6 MHM-maran on a run position

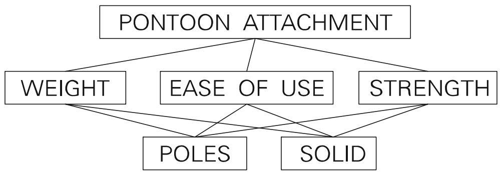

Fig. 6.7 Pontoon attachment

This design connects the two poles, and the tracks serve to provide the poles with movement, allowing the minor pontoon to swing around the main hull (Figs. 6.9 and 6.10).

The poles are strong, present no problem with respect to seaworthiness, and would be much lighter than a solid structure. Poles can also extend and retract, thus they are most suitable for the necessary pontoon swings.

Next we selected the material from which the pontoons would be built (see Fig. 6.11). The possibilities are fiberglass, aluminum, titanium and stainless steel. These materials happened to be the most resistant to rust. Titanium is light, strong but also very expensive and difficult to work with. Yet, it is a popular metal among the yacht racing community, because of its lightness and strength. Aluminum alloys are much cheaper than titanium and are sufficiently strong for most yachting needs. Aluminum is light, but much heavier than titanium. Fiberglass is good for salt water, but it is also heavy. It cannot undergo much direct stress. Stainless steel is relatively expensive and heavy, yet it is very strong.

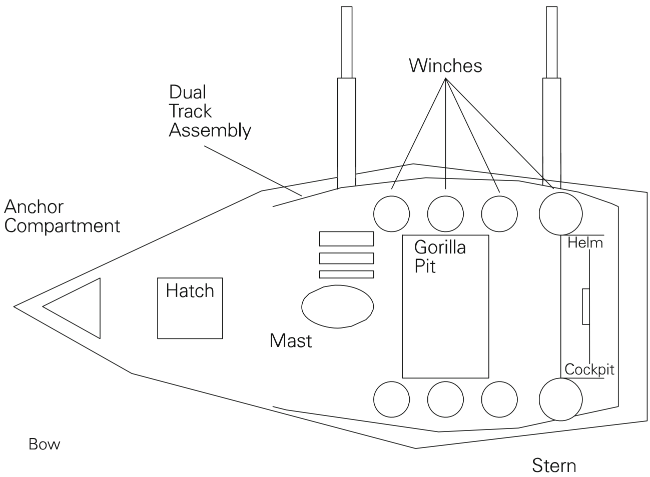

Fig. 6.8 Main hull

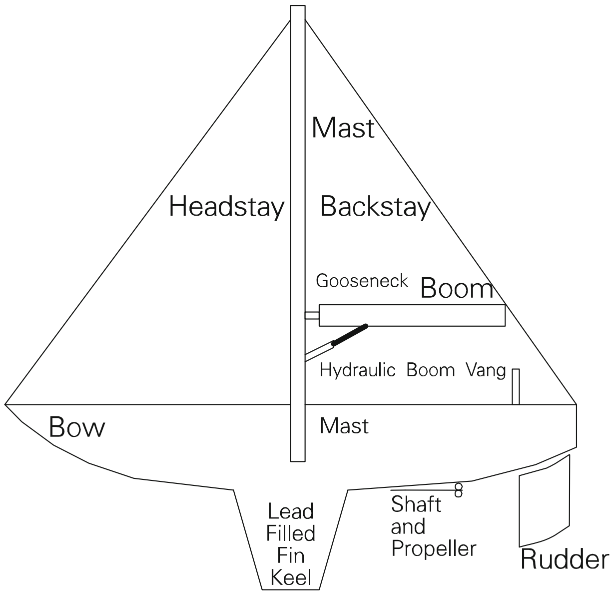

Fig. 6.9 Main hull side view

By having a dual track assembly follow the aft half of the major pontoon's toe rail (see Fig. 6.12) the minor pontoon would be mobile. It would be able to swing around to the leeward side (the side where the wind exits the surface of the boat) to minimize the MHM-maran degree of heel. On the run position, it would not matter which side the minor pontoon is positioned, since the wind is blowing from

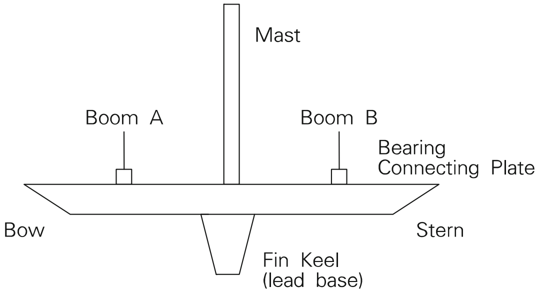

Fig. 6.10 Pontoon side view

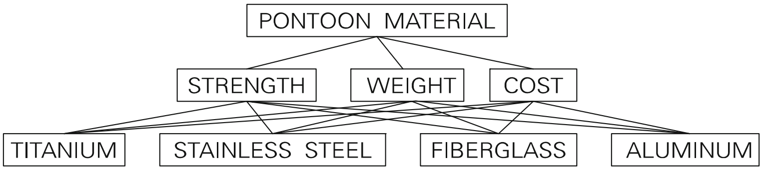

Fig. 6.11 Pontoon material selection

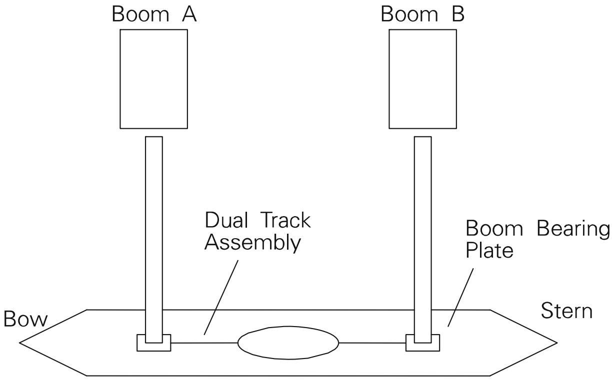

Fig. 6.12 Pontoon top view

behind. The evaluation of all materials with respect to strength, cost and weight gave rise to titanium as the most favored. This guarantees that a strong, and flexible connection would be made between both pontoons.

Criteria	Weights	Alternatives	Weights
Strength	0.648	Titanium	0.564
Weight	0.230	Stainless Steel	0.161
Cost	0.122	Fiberglass	0.063
		Aluminum	0.212

6.7 Conclusion

The hierarchic conceptualization of sailboat design yielded the unique MHM-maran structure. With one large and one small pontoon (connected by two poles made of titanium), a fin keel, spade rudder and a never before seen sail (maranaker), it offers many performance benefits to the sailor and it is being considered by a contemporary sailboat manufacturer. However, it may be expensive for the average sailor.

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Chapter 7
The Selection of a Bridge

7.1 Introduction

This chapter illustrates the use of the AHP for selecting the most appropriate bridge design in two different applications. The one recommended in the second application coincides with the decision that was actually made, demonstrating that the exclusion of an important, but hard to perceive actor, can alter the final decision. In this example we learn that decision making is not simply including multiple criteria in the decision, but more importantly the diverse people or groups who influence the outcome because of their own purposes.

By the close of the 1990s, the Golden Triangle Area in the City of Pittsburgh will once again be under construction to improve the flow of traffic into, out of, and through the city. The Mon Warf will be reconstructed, and the Fort Pitt Bridge will undergo rehabilitation. The Commonwealth Bridge Project is an effort by federal, state and local agencies to construct an alternative route across the Monongahela River to alleviate traffic congestion between the central business district of downtown Pittsburgh and Pittsburgh International Airport (Fig. 7.1). A new bridge, and a high occupancy vehicle (HOV) busway will be built to the Wabash Tunnel [3]. The bridge will consist of three HOV lanes and a lane for pedestrian traffic. The Port Authority and PennDOT want to begin construction by 1997, so that the new bridge will be open for use when the Fort Pitt Bridge is closed for rehabilitation. The cost of the entire busway project is estimated at $300 million, and estimates for the new bridge range from $30 to $40 million.

At the time of the writing of the two reports[1] on which this chapter is based, the bridge type had not been decided, although the second paper (a follow up on the first) did point to the bridge type that was chosen a few weeks later. The difference between the two approaches is the shift in emphasis among the stakeholders from

[1] See acknowledgments in the Preface.

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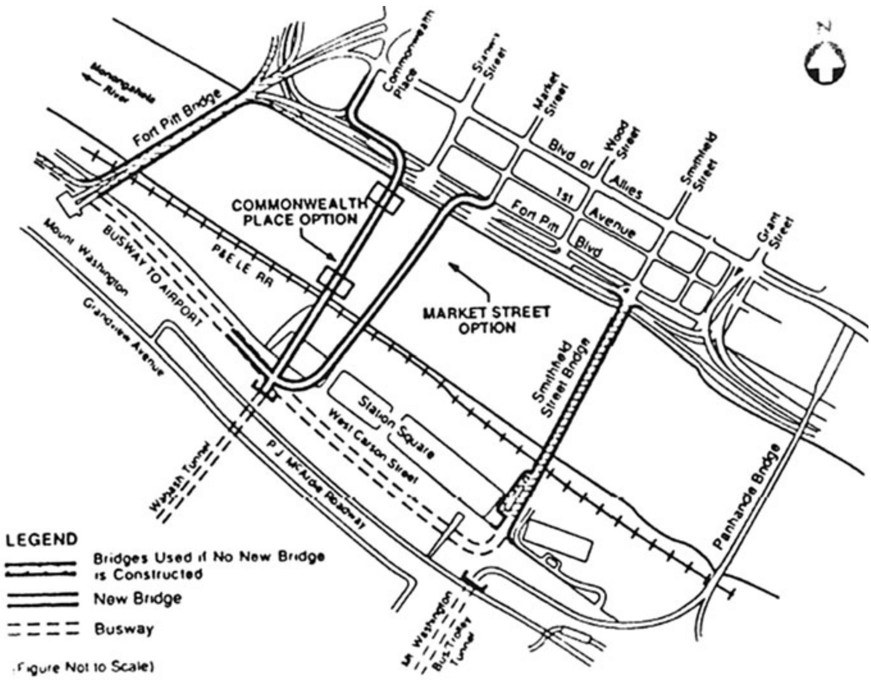


Fig. 7.1 Proposed commonwealth bridge location

the Public to the Coast Guard because of concern with safety and with the economic impact that the bridge would have on the area.

The bridge types considered by The Port Authority of Allegheny County (PAT) were: a Cable-stayed bridge, a Truss bridge, and a Tied-arch bridge.

7.2 Three Alternative Bridge Types

7.2.1 Cable-Stayed Bridges

Although the original concept of cable-stays dates back to Egyptian sailing ships, on which inclined ropes hanging from a mast were used to support a beam [1], it was not until the nineteenth century that the first cable-stayed bridge, the Roeblings bridge, at Niagara Falls New York, was constructed [4]. Built in 1855, it spanned 807 ft across a river gorge (Fig. 7.2).

Despite the fulfillment of this engineering feat, modern cable-stayed bridges were not considered feasible until shortly after World War II, when German engineers pioneered their development. The main hurdles were technology-based; the limitation of high strength materials, structural analysis and construction methods [2].

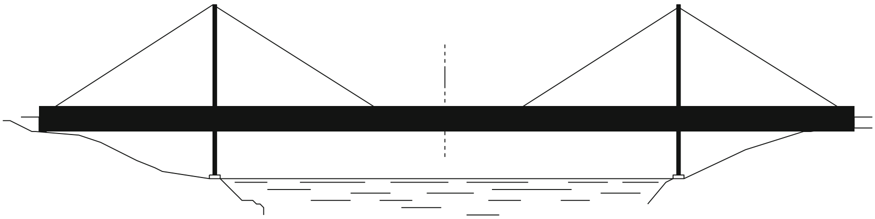


Fig. 7.2 The cable-stayed bridge

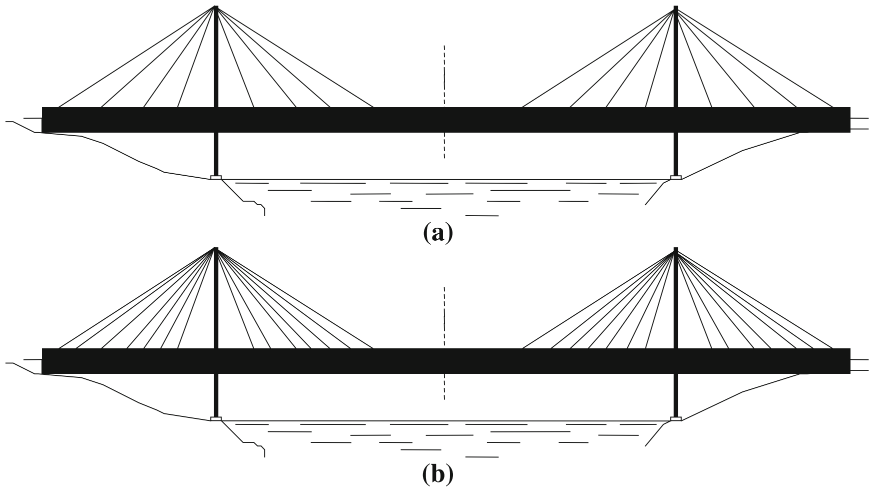


Fig. 7.3 **a** Cable-stay bridge with several cables. **b** Cable-stay bridge with cable separation reduced

To overcome design limitations, only cables with very high tensile strength are used. This minimizes beam deflection which becomes increasingly important as the span increases. Moreover, adding several stay cables allows the use of more slender deck beams (Fig. 7.3a) which require less flexural stiffness. By decreasing the cable spacing supports (Fig. 7.3b), local bending moments in the girders are also reduced.

The second presupposition for the success of cable-stayed bridge types is the simplification of the deck cross-section. Simple double-edge girders supporting transverse floor beams and top slabs provide a synergistic reinforcing action. As a result, the deck structure acts as a unit over intermediate supports.

Because of their aesthetically pleasing form, cable-stayed bridges can be found in almost all modern cities. The early cable-stayed bridges in North America were mostly constructed from steel because that was the traditional method at the time.

However, due to the high cost of material and labor the all-steel bridge has been losing competitiveness. To address this decline, modern designers have developed an orthotopic composite deck, a concrete deck slab supported by steel framing. Today, virtually all cable-stayed bridges contain an orthotopic deck.

The economic viability and aesthetic appeal of the cable-stayed bridge make it the most popular bridge type for spans ranging between 650 and 1650 ft. In North America there were 25 cable-stayed bridges constructed or under development in the 20 years between 1971 and 1993.

7.2.2 Truss Bridges

Truss bridges have been used in North America for decades. A truss may be described as a triangulated assembly of straight members. The design of the truss structure [2] allows applied loads to be resisted primarily by axial forces in its straight truss members; the truss proper is loaded only at the nodes or intersection of straight members. It is a very efficient and sturdy design.

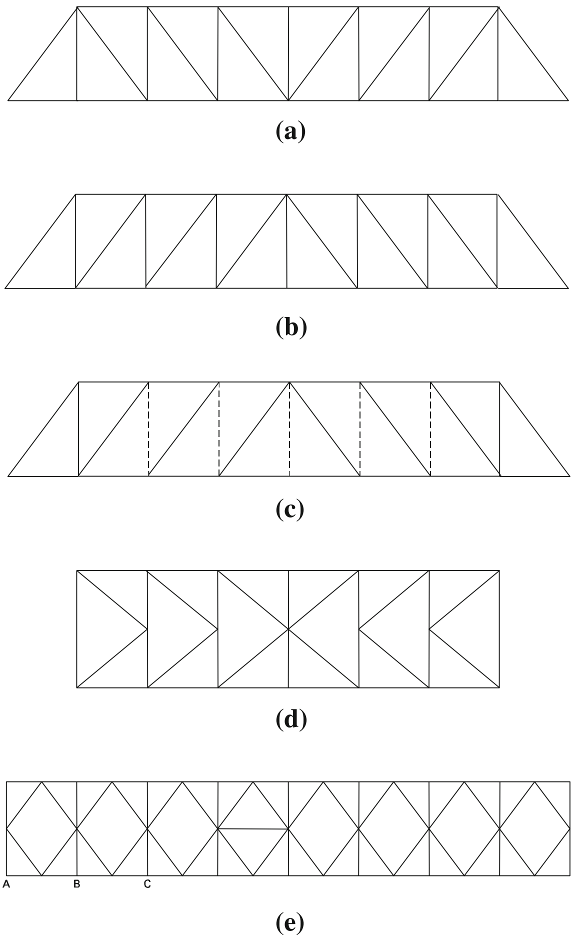
Figure 7.4 shows five main types of trusses, each providing a slight variation in load distribution. Also included in this figure is a general illustration of the Warren Truss bridge. The two most common are the Pratt and the Warren designs. Bridge design is typically performed on a case-by-case basis considering variables such as traffic, durability, and dependability.

A truss bridge has two major structural advantages [2]: (a) The primary member forces are axial loaded; (b) the open web system permits the use of a greater overall depth than for an equivalent solid web girder. Both factors lead to economy in material and a reduced dead weight. Increased depth results in reduced deflections, and a more rigid structure. These advantages are achieved at increased fabrication and maintenance costs.

The conventional truss bridge is typically most economical for medium spans (500–1,500 ft). Traditionally it has been used for spans intermediate between the plate girder and the stiffened suspension bridge designs. Modern construction techniques have tended to increase the economical span of both steel and concrete girders. Thus the steel truss bridge is a direct competitor to the cable-stayed for intermediate spans. The relative lightness of a truss bridge is advantageous because it can be assembled part-by-part using lifting equipment of small capacity. Alternatively, the number of field connections may be supplanted by pre-assembly.

From an architectural perspective the truss bridge rarely possesses aesthetic beauty. This is partly due to the complexity of the intersection of its load bearing component. In bridges of moderate span, it appears best to provide a simple and regular structure. For this reason, the Warren truss usually looks better than other forms.

Fig. 7.4 Five of the most common truss type bridges **a** Pratt truss, **b** Howe truss, **c** Warren truss, **d** K-bracing system, **e** Diamond bracing system

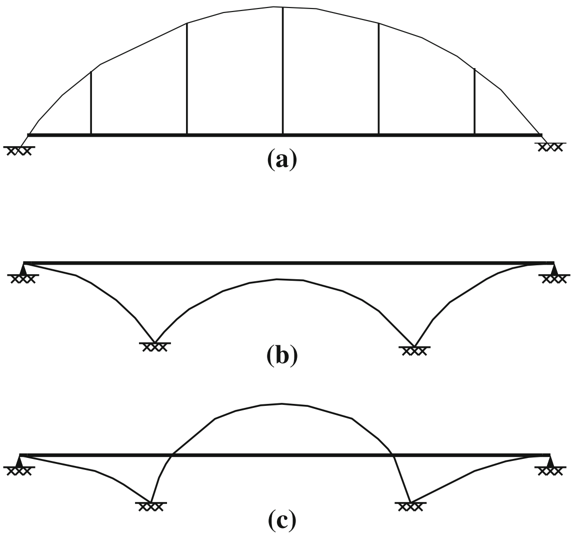


7.2.3 Tied-Arch Bridges

The structural form of the arch has been used for its architectural beauty and outstanding strength for centuries. Because of the manner in which it distributes the applied load [2], with the aid of inward-acting horizontal components, the arch is capable of distributing loads both above and below its structure. In a tied arch design, the horizontal reactions to the arch rib are supplied by a tie at deck level. Figure 7.5 illustrates common tied-arch bridge types.

Some of the distinguishable features of the tied-arch are that it reduces bending moments in the superstructure and is fairly economical to construct relative to an equivalent straight, simple supported girder or truss [2].

Fig. 7.5 Three common tied-arch bridge types



Aesthetically, the arch has been the most appealing of all bridge types. Its appearance is familiar and expressive. The curved shape is always pleasing to view.

The disadvantages of the tied-arch are probably its high relative fabrication and building costs. The conventional curved arch rib usually entails the highest expense. Building problems vary with structure type, with the least problematic structure being the cantilever-arch and the tied-arch possibly being the most difficult. The difficulty with the latter arises from the fact that the horizontal reactions are not available until the deck is completed.

7.3 The Decision Making Process

The most desirable bridge type would conceivably be the one which brings the most satisfaction to the greatest number of stakeholders. Using this goal, a hierarchy (see Fig. 7.6) was developed with major stakeholders at the second level, the driving criteria at the third level and the three alternative bridge types at the fourth level.

7.3.1 Stakeholders

Published reports have estimated the number of stakeholders involved in this project to be in the hundreds. The most important stakeholders were aggregated into seven broad groups. Commonality within the groups was maintained. The identifiable groups are: a federal agency, the commercial business district, the public, state

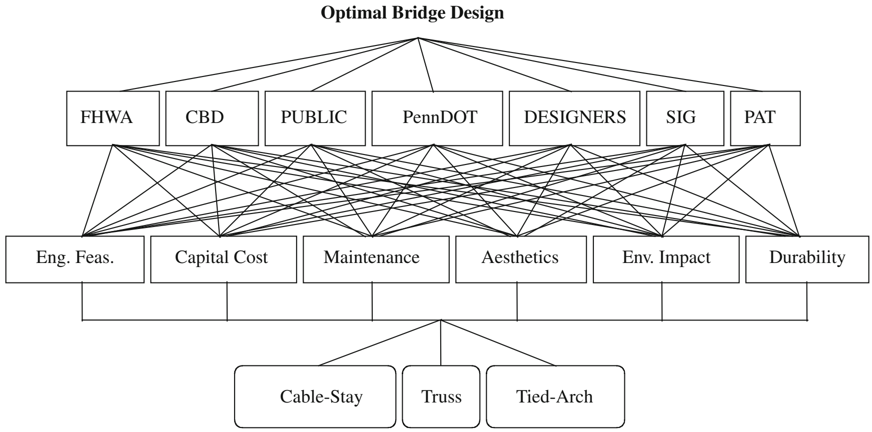


Fig. 7.6 Bridge selection hierarchy

agencies, the Port Authority Transit, the designers, and special interest groups such as concrete suppliers, steel manufacturers, environmentalists and others.

A Federal Agency (FHWA) represents an array of federal departments. They are a key financier of the project and will have dictates with respect to the engineering integrity of any bridge type.

The Commercial Business District (CBD) broadly represents the businesses in downtown Pittsburgh. However, with respect to bridge type it is suggested that Station Square is the dominant entity because of the interest in maintaining the historical appearance of the site.

The Public represents the population of Pittsburgh which would use the new service (and the bridge itself).

The Pennsylvania Department Of Transportation (PennDOT) represents the complex interest of the state. These interests are financial (as the state provides part of the capital), political, technical and environmental.

The Designers represent engineers, architects and planners and their representative professional organizations. It is recognized that designers provide crucial technical input and, as such, are strategically positioned to influence the decision making process.

The Port Authority Transit (PAT) is the ultimate project owner. They are responsible for all management issues from conception to construction, as well as subsequent maintenance. This makes them a premier stakeholder.

Special Interest Groups (SIG) is a very broad category with diverse and possibly conflicting interests. With regard to the bridge type the three most significant special interest groups are likely to be: concrete suppliers, steel manufacturers and environmentalists. The indigenous steel industry of Pittsburgh has declined in size and influence in recent times; however, the concrete industry remains strong. Environmentalists are active and sometimes vocal.

7.3.2 Criteria

In the level below the stakeholders are the criteria which drive the decision making process. The most important criteria are:

Engineering Feasibility (EF): The technical knowledge and experience of both the designers and contractors in regard to the bridge type.

Capital Cost (CC): Necessary funding.[2] Because the costs were committed, low costs are included in the overall benefits hierarchy as one the criteria.

Maintenance (MA): General cleaning, painting and inspection vary dramatically with bridge type.

Aesthetics (AE): Architectural attractiveness.

Environmental Impact (EI): The ecological and historical adjustments that must be compromised.

Durability (DU): The life of the bridge and the potential major repairs over and above routine maintenance.

7.4 Judgements and Decisions

To find the most desirable bridge design, the actors were compared to determine their relative influence (Table 7.1). The stakeholder ranking, as suggested by the authors in order of importance, is PAT (0.337), CBD (0.221), Federal Agency (0.136), State Agencies (0.136), Designers (0.085), Special Interests (0.056) and the Public (0.029). The criteria were then compared according to each actor and the composite relative priorities calculated (Table 7.2). Finally, the alternatives were compared according to the criteria and the final priorities computed.

This information was synthesized to yield the most desirable bridge type which was determined to be the Truss type bridge.

The priorities of the three alternatives are:

Truss bridge	0.371
Tied-arch bridge	0.320
Cable-stayed bridge	0.309

[2] The cable-stayed bridge type is very efficient in terms of section sizes and material used. However, there is limited experience with their use in the State of Pennsylvania. As a result, the capital costswould vary greatly depending on the tender procedureused (statewide, nationwide or international).

Table 7.1 Actors' comparisons

	FHWA	CBD	Public	PennDOT	Designers	SIG	PAT
FHWA	1	2	1/5	1	1/2	1/3	3
CBD	1/2	1	1/6	1/2	1/3	1/4	2
Public	5	6	1	5	4	3	7
PennDOT	1	2	1/5	1	1/2	1/3	3
Designers	2	3	1/4	2	1	1/2	4
SIG	3	4	1/3	3	2	1	5
PAT	1/3	1/2	1/7	1/3	1/4	1/5	1

Table 7.2 Priorities of the criteria

	0.135 FHWA	0.221 CBD	0.029 Public	0.136 PennDOT	0.085 Designers	0.056 SIG	0.337 PAT	Priorities
EF	0.117	0.048	0.037	0.216	0.313	0.033	0.260	0.173
CC	0.340	0.048	0.297	0.082	0.197	0.357	0.100	0.147
MA	0.069	0.116	0.297	0.052	0.118	0.097	0.260	0.154
AE	0.069	0.401	0.074	0.216	0.136	0.224	0.061	0.174
EI	0.202	0.270	0.114	0.352	0.117	0.224	0.061	0.181
DU	0.202	0.116	0.182	0.082	0.118	0.064	0.260	0.171

7.5 Bridge Selection Revisited

The analysis just presented was prepared by MBA students. Several months following the foregoing analysis another MBA student revisited the decision and sought validation with two individuals closely involved in the bridge selection process. The hierarchy developed in this second approach is given in Fig. 7.7 and the results are provided in Table 7.3. Note that the hierarchy used is similar to the one given in Fig. 7.6. However, the elements in the levels are not identical to the ones in the first approach. The major difference between the two approaches is the addition of a new stakeholder, the U.S. Coast Guard, and the deletion of The Public.

United States Coast Guard (USCG): River transportation has a significant impact on the economy of Pittsburgh and the surrounding area in Western Pennsylvania. Since there will be three bridges in close proximity to one another (Smithfield Street, Monongahela River, and Fort Pitt), ample room must be maintained for river traffic. The Coast Guard will also want to minimize the impact of the bridge construction on river traffic.

Tied-arch bridge:	0.471
Cable-stayed bridge:	0.328
Truss bridge:	0.201

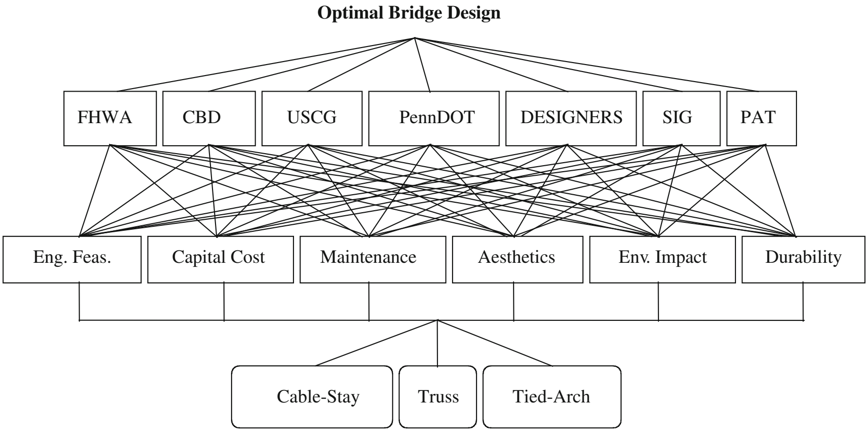


Fig. 7.7 Hierarchy for the revised bridge decision

Table 7.3 Priorities of the criteria for the revisited bridge decision

	0.173 FHWA	0.087 CBD	0.118 USCG	0.173 PennDOT	0.036 Designers	0.051 SIG	0.361 PAT	Priorities
EF	0.218	0.048	0.214	0.220	0.346	0.228	0.230	0.212
CC	0.354	0.137	0.043	0.344	0.248	0.100	0.121	0.195
MA	0.053	0.083	0.161	0.053	0.070	0.046	0.230	0.132
AE	0.073	0.400	0.067	0.114	0.155	0.432	0.121	0.146
EI	0.189	0.249	0.383	0.191	0.129	0.148	0.070	0.170
DU	0.112	0.083	0.123	0.078	0.052	0.046	0.230	0.142

The priorities of the three alternatives are now:

It must be noted that another important difference between the two approaches, in addition to the ones mentioned above, is the group of decision makers providing the judgments. Although in both occasions judgments were provided by people with good information on the project, the second time the judgments were given by the two individuals close to the committee that made the final recommendation of the tied-arch type bridge.

7.6 Conclusion

The AHP was used to select the best alternative (the Tied-arch type bridge) from among closely competing alternatives. It also facilitated the learning process and gave users a more thorough understanding of the competing factors in a complex decision making environment. It illustrates the sensitivity of the outcome to what factors one chooses to include. It is certain that so far major public works divisions have not been as thorough and comprehensive as may be needed to ensure the success and longevity of an important project. More examples of such applications need to be brought to the attention of authorities for better value and longer lasting performance.

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Chapter 8
Measuring Dependence Between Activities: Input–Output Application to the Sudan

8.1 Introduction

In this chapter we illustrate how to deal with dependence among the elements of the same level of a hierarchy (inner dependence) with an application we made in the design of the Transportation System for the Sudan (see [2]). The outcome of this analysis was an input–output table which parallels the work of econometricians. This application was done a few years after the Sudan Transport Study was finished.

Input–output matrices in economics are generally obtained as follows. Let A_1, $A_2, \ldots, A_N$ denote N sectors of an economy and let S be a matrix whose s_{ij} entry indicates the output from sector i which becomes an input to sector j. Let Y_j be the net contribution from sector i to the final (consumer) demand. We have: $\sum_{i=1}^{N} s_{ij} = S_j$ total intermediate output of sector j (domestic needs from other sectors) $S_j + Y_j = O_j$ total output of sector j. The technological coefficients are obtained as follows $\frac{s_{ij}}{S_j + Y_j} = w_{ij}$ (contribution of sector i to produce a unit of output j)

$$\frac{s_{ij}}{S_j + Y_j} = \left(\frac{s_{ij}}{S_j}\right)\left(\frac{S_j}{S_j + Y_j}\right) = \frac{s_{ij}\, S_j}{S_j\, O_j}$$

To obtain the matrix of technological coefficients by the AHP we must estimate s_{ij}/S_j and S_j/O_j. Let us see what these represent. $S_j/(S_j + Y_j)$ represents the proportion of the total output of sector j allocated to domestic consumption. The total output is estimated, for $j = 1,\ldots, N$, by means of the AHP by asking the following question: How strong is one sector compared to another when allocating outputs to domestic needs? If this question cannot be answered directly, domestic needs may be hierarchically decomposed into production, demand, labor, capital, and cost. These sectors are prioritized separately with respect to each criterion. After prioritizing these criteria according to their impact on production, composition is

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used to obtain an overall measure of importance for the sectors. Let us denote the estimates of (S_j/O_j) by x_j.

Again s_{ij}/S_j represents the proportion of the total intermediate output from sector i allocated to sector j. We have

$$\sum_{i=1}^{N} s_{ij}/\, S_j = 1$$

We construct a matrix of pairwise comparisons among the sectors as they relate to sector i. We answer the following question. How strong is the dependence of one sector in comparison with another in receiving output from sector j? The result is a matrix of pairwise comparisons which yields a column eigenvector of weights. When this is done for each sector we obtain a matrix W whose columns are these eigenvectors.

Finally, we take the elementwise product of each column of the matrix W with the column vector $x = (x_1, x_2,\ldots, x_N)$ to obtain the estimates of the technological coefficients, i.e., the input–output matrix.

The most important fact we have to take into consideration when the matrix of technological coefficients is estimated using the AHP is the proportion of total intermediate outputs for each sector in relation to the total output. This proportion was estimated in this example by extensive study of the literature on the Sudanese economy available at the time [1].

8.2 Application

The Sudan is considered to be mainly an agricultural country. At the time the econometric models were constructed (1973) and the input–output analysis was done, the data used were from the year 1961. At this time, the major problem of the Sudan was the lack of an adequate transport system.

We considered the following six sectors.

(1) Agriculture (AGR)
(2) Public utilities (PU)
(3) Manufacturing and mining (M&M)
(4) Transportation and distribution (T&D)
(5) Construction (CONS)
(6) Services (SERV)

To make the same order of magnitude comparison with Agriculture and Transportation (another major activity), the other sectors were grouped into an aggregate.

The question to be asked to form the matrices of pairwise comparisons is: Given two sectors, i and j, which sector allocates more of its outputs to satisfy domestic needs (total intermediate outputs)? We first compare the elements in the aggregate, then separately compare the aggregate with agriculture and transport and use the resulting weight of the aggregate to compose the relevant weights from the four sectors in the aggregate itself. To save space we have not written out justifications of the judgments, which are available in a separate study.

	Satisfaction of domestic needs	PU	M&M	CONS	SERV	Eigenvector
AGG:	PU	1	1/2	1/2	1/3	0.1272
	M&M	2	1	1	1	0.2804
	CONS	2	1	1	1	0.2804
	SERV	3	1	1	1	0.3120

$\lambda_{max} = 4.02$, C.I. $= 0.007$, C.R. $= 0.007$

Satisfaction of domestic needs	AGR	T&D	AGG	Eigenvector
AGR	1	1/2	2	0.3108
T&D	2	1	2	0.4934
AGG	1/2	1/2	1	0.1948

$\lambda_{max} = 3.05$, C.I. $= 0.025$, C.R. $= 0.04$

For the relative importance of the sectors we have:

Sectors	Final weights $S_i/(S_i + Y_i)$	Estimates of $Y_i/(S_i + Y_i)$
1	0.3108	0.6892
2	0.0248	0.9752
3	0.0546	0.9454
4	0.4934	0.5066
5	0.0546	0.9454
6	0.0608	0.9392

Now we identify the relationships among the sectors. They are given by the rows of the following table.

I.O.	AGR	PU	M&M	T&D	CONS	SERV
AGR	X		X	X	X	
PU	X		X	X		X
M&M	X			X	X	X
T&D	X	X	X		X	X
CONS						X
SERV		X	X	X	X	X

Given a certain sector *i* we ask: for any two sectors, *h* and *k*, to which sector are more products from sector *i* allocated? The following treatments answer this question for each sector.

Agriculture

The main crop in the Sudan is cotton. Cotton is exported and also allocated to the manufacturing sector. Thus agriculture, transportation and distribution, and construction do not receive a large amount of agricultural products. A new aggregate is formed. (Note that only four sectors are considered under agriculture.)

$$\begin{array}{c}\text{Aggregate}\\ \text{(AGG)}\end{array}\left\{\begin{array}{c}\text{Agriculture}\\ \text{Transport and Distribution}\\ \text{Construction}\end{array}\right.$$

As we pointed out above, the Sudan lacks adequate transportation. We aggregated the two sectors which do not consume substantial quantities from agriculture, AGR and T&D, because, although the main crop after cotton is wheat, the agricultural sector allocates most of its output (i.e., wood) to construction. Transportation is developed by means of loans from Arab oil countries and the World Bank. Thus, we also aggregated agriculture and transportation to form a subaggregate.

	Input from agriculture	AGR	T&D	Eigenvector
SUBAGG:	AGR	1	9	0.9000
	T&D	1/9	1	0.1000

$\lambda_{\max} = 2.0$, C.I. $= 0.0$, C.R. $= 0.0$

	Input from agriculture	SUBAGG	CONS	Eigenvector
AGG:	SUBAGG	1	1/9	0.1000
	CONS	9	1	0.9000

$\lambda_{\max} = 2.0$, C.I. $= 0.0$, C.R. $= 0.0$

Input from agriculture	AGG	M&M	Eigenvector
AGG	1	1/3	0.25
M&M	3	1	0.75

$\lambda_{\max} = 2.0$, C.I. $= 0.0$, C.R. $= 0.0$

Sectors	Final weights
AGR	0.0225
PU	0.0000
M&M	0.7500
T&D	0.0025
CONS	0.2250
SERV	0.0000

Note The weights of AGR and T&D are obtained as follows.

$$\begin{array}{r} AGR \\ T\&D \end{array}\begin{bmatrix} 0.9 \\ 0.1 \end{bmatrix} \times (0.1) \times (0.25) = \begin{bmatrix} 0.0225 \\ 0.0025 \end{bmatrix}$$

The weight of construction is obtained by multiplying (0.9) by (0.25) = 0.225.

Public Utilities

Input from PU	AGR	M&M	T&D	SERV	Eigenvector
AGR	1	1/9	1/7	1/5	0.0410
M&M	9	1	2	5	0.5242
T&D	7	1/2	1	3	0.3030
SERV	5	1/5	1/3	1	0.1318

$\lambda_{\max} = 4.12$, C.I. = 0.04, C.R. = 0.04

Manufacturing and Mining

Input from M&M	AGR	T&D	CONS	SERV	Eigenvector
AGR	1	1/2	1/9	1	0.0758
T&D	2	1	1/5	3	0.1628
CONS	9	5	1	9	0.6941
SERV	1	1/3	1/9	1	0.0681

$\lambda_{\max} = 4.03$, C.I. = 0.01, C.R. = 0.01

Transportation and Distribution

Input from T&D	AGR	PU	M&M	CONS	SERV	Eigenvector
AGR	1	1/3	1/2	1/2	7	0.1400
PU	3	1	1	2	9	0.3434
M&M	2	1	1	1	7	0.2596
CONS	2	1/2	1	1	7	0.2260
SERV	1/7	1/9	1/7	1/7	1	0.0310

$\lambda_{\max} = 5.11$, C.I. = 0.03, C.R. = 0.03

Construction

Construction only gives its products to services. Thus we associate the value 1 with services.

Services in the Sudan are very poor. We have assumed that the allocation of service outputs to services, and to construction, are so negligible that these two could be aggregated. We have

$$\text{Aggregate (AGG)} \begin{cases} \text{Construction} \\ \text{Services} \end{cases}$$

	Input from services	CONS	SERV	Eigenvector
AGG:	CONS	1	9	0.9000
	SERV	1/9	1	0.1000

$\lambda_{\max} = 2.0$, C.I. $= 0.0$, C.R. $= 0.0$

Services

Input from services	PU	M&M	T&D	AGG	Eigenvector
PU	1	1/2	1/2	3	0.1930
M&M	2	1	1	5	0.3680
T&D	2	1	1	5	0.3680
AGG	1/3	1/5	1/5	1	0.0704

$\lambda_{\max} = 4.004$, C.I. $= 0.001$, C.R. $= 0.001$

The weights of construction and services are obtained by multiplying 0.0704, the weight of the aggregate, by 0.9 and 0.1, respectively.

Sectors	Final weights
AGR	0.0000
PU	0.1930
M&M	0.3680
T&D	0.3680
CONS	0.0634
SERV	0.0070

The matrix whose rows are the foregoing eigenvectors gives the distribution of total intermediate outputs to the sectors. It is given by the following table.

Shares of the total intermediate outputs — Producers

$$\begin{array}{c} \\ \text{AGR} \\ \text{PU} \\ \text{M\&M} \\ \text{T\&D} \\ \text{CONS} \\ \text{SERV} \end{array} \begin{array}{c} \begin{array}{cccccc} \text{AGR} & \text{PU} & \text{M\&M} & \text{T\&D} & \text{CONS} & \text{SERV} \end{array} \\ \begin{bmatrix} 0.0225 & 0 & 0.7500 & 0.0025 & 0.2250 & 0 \\ 0.0410 & 0 & 0.5242 & 0.3030 & 0 & 0.1318 \\ 0.0750 & 0 & 0 & 0.1628 & 0.6841 & 0.0681 \\ 0.1400 & 0.3434 & 0.2596 & 0 & 0.2260 & 0.0310 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0.1939 & 0.3683 & 0.3683 & 0.0634 & 0.0004 \end{bmatrix} \end{array}$$

At the beginning we computed how strongly the sectors allocate outputs to domestic needs. The vector of weights was:

AGR	PU	$M\&M$	$T\&D$	$CONS$	$SERV$
0.3108	0.0248	0.0546	0.4934	0.0546	0.0608

Thus we multiply each column of the above matrix by this vector (element-wise multiplication), e.g., for the first column we have

$$\begin{bmatrix} 0.0225 \times 0.3108 \\ 0.0410 \times 0.0248 \\ 0.0750 \times 0.0546 \\ 0.1400 \times 0.0546 \\ 0 \quad \times 0.0546 \\ 0 \quad \times 0.0608 \end{bmatrix} = \begin{bmatrix} 0.0070 \\ 0.0009 \\ 0.0041 \\ 0.0691 \\ 0 \\ 0 \end{bmatrix}$$

The weighted matrix is then given by:

$$\begin{array}{c} \\ AGR \\ PU \\ M\&M \\ T\&D \\ CONS \\ SERV \end{array} \begin{array}{c} \begin{array}{cccccc} AGR & PU & M\&M & T\&D & CONS & SERV \end{array} \\ \begin{bmatrix} 0.0070 & 0 & 0.2331 & 0.0008 & 0.0699 & 0 \\ 0.0009 & 0 & 0.0130 & 0.0075 & 0 & 0.0033 \\ 0.0041 & 0 & 0 & 0.0089 & 0.0379 & 0.0037 \\ 0.0691 & 0.1694 & 0.1281 & 0 & 0.1115 & 0.0153 \\ 0 & 0 & 0 & 0 & 0 & 0.0546 \\ 0 & 0.0117 & 0.0117 & 0.0224 & 0.0039 & 0.0004 \end{bmatrix} \end{array}$$

If we compare this matrix with the following input–output matrix obtained by traditional methods, we see that there are very minor differences.

$$\begin{array}{c} \\ AGR \\ PU \\ M\&M \\ T\&D \\ CONS \\ SERV \end{array} \begin{array}{c} \begin{array}{cccccc} AGR & PU & M\&M & T\&D & CONS & SERV \end{array} \\ \begin{bmatrix} 0.00737 & 0 & 0.21953 & 0.00042 & 0.06721 & 0 \\ 0.00024 & 0 & 0.01159 & 0.00618 & 0 & 0.00283 \\ 0.00393 & 0 & 0 & 0.00857 & 0.04216 & 0.00322 \\ 0.06993 & 0.14536 & 0.12574 & 0 & 0.09879 & 0.00641 \\ 0 & 0 & 0 & 0 & 0 & 0.05402 \\ 0 & 0.0103 & 0.02549 & 0.02422 & 0.0052 & 0.00021 \end{bmatrix} \end{array}$$

The factors considered in this problem were purely economic. This suggests that this type of analysis can be extended to study social systems and particularly to introduce social factors in the resource allocation problem when the activities are interrelated (a problem briefly mentioned by V. Leontief, the founder of input–output analysis).

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Chapter 9
Technological Choice in Less Developed Countries

9.1 Introduction

It is widely believed that the economic situation of less developed countries (LDCs) can be greatly improved by conscious and judicious application of science and technology to the solution of their many problems. This belief is well supported by evidence attributing the rapid economic growth achieved by industrially advanced countries to the technology factor [1, 13]. Early economic theorists noted that the level of savings and investment in the LDCs was low. They recommended transfusion of capital to spur investment and capital formation; but beginning with the late fifties the emphasis shifted to transfusion of technology rather than capital. However, the collective experience of the LDCs with imported technology over the past three decades has been far from encouraging, as is apparent from the growing discontent voiced by the "Group of 77."

A substantial body of literature attempts to grapple with the problem of transferring technology effectively to the LDCs (for example, [4, 10, 13, 15]). This literature represents a significant part of the scholarly output in the broader area of technology transfer and technological innovation. We make no attempt here to survey the literature on technology transfer in general, or even international technology transfer in particular, but will merely note that the problem has been approached from a number of different perspectives, with contributions from economists, sociologists, anthropologists, political scientists, and technical professionals. Some are concerned with the "how to" of technology transfer; that is, with the mechanisms and methods of transfer. Some describe the process of technology transfer and diffusion. Yet others critically assess the consequences of transferring advanced technology to less developed countries and appear to be voicing concern about a rather fundamental question: the "why" of technology transfer. These varied disciplinary approaches indicate the complexity of factors impinging on technological choice in the LDCs.

T. L. Saaty and L. G. Vargas, *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*, International Series in Operations Research & Management Science 175,
DOI: 10.1007/978-1-4614-3597-6_9,

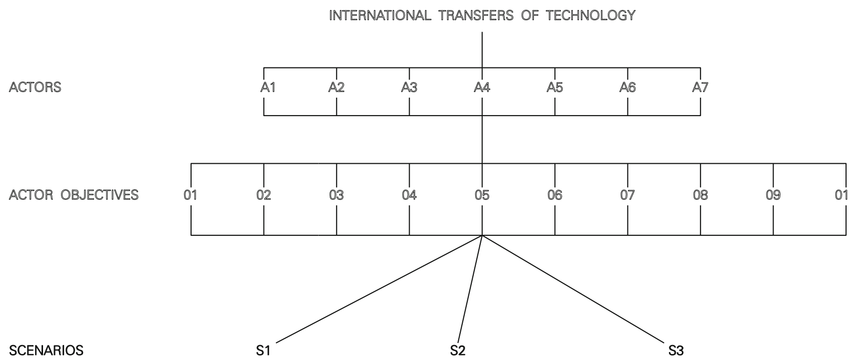
The field is rich in conceptualizations and historical accounts of the ways in which technology has been transferred among today's advanced countries. With respect to theories, one can mention the notion of the "technology gap" [5]; the product life cycle hypothesis [16]; and the depiction of the diffusion process as a logistic or S-shaped curve [9], which has stood empirical validation in economic studies [3, 6]. These theories have yet to be integrated into an overall framework that would provide guidance to planners involved in technology transfer. All are vulnerable to the criticism of being limited in scope. A recent body of literature views technology transfer as a bargaining process between economically unmatched participants in an imperfect market. Prescriptions for the LDCs range from moving toward an alternative model of development that emphasizes the small and the human [12] to a more "pragmatic" emphasis on developing integrated science and technology policies based on needs and goals, building up local research and development capabilities to better assimilate imported technologies as well as develop indigenous ones, and exploring avenues for regional economic and technological cooperation with other LDCs.

Two dominant and somewhat opposing themes emerge from a survey of the literature on international transfers. One focuses on the process of imitation, while the other considers technological change as predicated on sociocultural change. The latter asserts that unless a revolution occurs whereby social attitudes and values are rapidly transformed, externally introduced technologies cannot operate optimally in the social environment of the LDCs. It is possible to take a balanced approach, one that acknowledges the importance of imitation as well as the sociocultural barriers, and because of their obvious interdependence, allows for them to proceed simultaneously.

Most discussions of technology transfer have paid little attention to methodologies for the assessment of technology. The available ones [7] do not appear well suited to the needs of LDCs because most have as their aim the prediction of technological futures. Here we present an integrated approach to technological assessment, choice, and transfer and analyze its possible impacts on the sectors of the economy of LDCs. After the potentially most useful technologies are identified, a benefit/cost framework is developed to also consider non-technological factors that may influence economic development.

9.2 Applications to Technology Transfer

In dealing with the problem of technology transfer, the AHP can be applied at several levels. At a global level, one might be interested in predicting, in general terms, the future course of technology transfers to the LDCs. A hierarchical representation of this problem is depicted in Fig. 9.1. At the first level of the hierarchy, we list the following actors who might be expected to play a role in determining the future course of technology transfers: the governments of the developed nations, the governments of the LDCs, "neutral" third parties such as



ACTORS

A1 = Governments of the developed countries
A2 = LDC governments
A3 = UN agencies (UNDP, UNCTAD, etc.)
A4 = USSR and Eastern Bloc Nations
A5 = Multinational Corporations
A6 = Small and big businesses in the LDCs
A7 = Labor unions

ACTOR OBJECTIVES

01 = Technological Leadership
02 = Trade in Goods and Services
03 = Balance of Payments
04 = Employment Generation
05 = Nationalism, Regionalism
06 = Expansion, Growth, Profits
07 = Political Leverage
08 = Preservation of own Culture, Environment
09 = Social Justice
010 = Protection of Domestic Enterprises

SCENARIOS

S1 = "Optimistic": Increased technological dependence and exchange
S2 = "Status Quo"
S3 = "Pessimistic": Concentration, localized integration, 'Closed door' policies in technology transfer

Fig. 9.1 Technology transfer hierarchy

the many United Nations organizations involved in technology transfer issues, the USSR and Eastern bloc nations, multinational corporations, the private sector as represented by big and small businesses, and labor unions. Each actor pursues a set of objectives such as technological leadership, trade, balance of payments, employment generation, economic expansion, and so on, vis-à-vis technology transfer. These objectives, spelled out in greater detail in Fig. 9.1, constitute the second level of the hierarchy. At the third level we indicate the future scenarios: an optimistic scenario that envisages increased flow of technology to the LDCs and among world nations in general, a scenario that is merely the extension of the status quo into the future, and a pessimistic scenario that foresees substantial reduction in the overall volume of trade in technology. Increased flow of technology could occur if, for instance, the much debated code of conduct for technology transfer and the international economic order should become realities. The pressures of the different actors and the strength with which they pursue current policies could result in indefinite extension of the status quo, or the continued impasse regarding technology transfer issues could deflect the LDCs toward policies of self-reliance and regional cooperation, thereby reducing the flow of technology from the advanced to the less developed countries.

To estimate the likelihood of the three scenarios, we first make a pairwise comparison of the relative influence of the different actors, which yields a set of weights for this factor. Next the objectives of each actor are compared in pairwise fashion in terms of their importance to the concerned actor. We pose questions such as: "How important is objective O1 relative to objectives O2, O3, and so on, for actor A1?" Having prioritized the objectives of each actor in this way, we apply the weights of actor influence to these objectives to obtain a set of weighted objectives. The process is continued by comparing the scenarios with respect to their relative contribution to the achievement of each objective and by weighting the scenario priorities by the weighted objectives. This results in an index of the overall likelihood or importance of each scenario.

For the purpose of illustration, we have limited the hierarchy to only three levels. The richness of the hierarchy can be extended as necessary by adding more levels and more elements within each level. For instance, a level of actor policies could be interposed between the objectives and scenarios, which might relate to taxation, imports and exports, degree of encouragement given to foreign ownership of capital, preferential treatments accorded to countries as sources of supply of goods and technologies, and so on.

Let us now see how this approach can be used to enable planners of an LDC to make technological choices. A survey of the literature suggests that the following criteria are paramount in technology transfer:

1. *Need*: Technology has to be tailored to the needs of the country. Need can be defined in terms of *suitability* and *urgency*. A technology might be considered suitable if it is proven to meet similar needs in other contexts. Needs will be influenced by overall national sectoral priorities.
2. *Adaptability*: It must be possible to adapt the technology to the local environment. Two considerations determining adaptability are the *ability* and the *willingness* to adapt. The lack of a sufficient science and technology base in terms of the availability of skilled manpower, maintenance facilities, materials in sufficient quantity and quality, presence of facilitating institutions and change agents, and the like, affects the ability to adapt. The willingness to adapt depends on the strength of custom, tradition, power relationships within the society, and similar social, cultural, and political considerations.
3. *Relative freedom from the risk of obsolescence*: Here our attention is focused on what may be termed "mass" technologies—technologies whose interface with the eventual user is close and extensive. Many of these technologies are certain to involve substantial investment. In the context of an LDC, the technology transferred must be capable of being supported throughout its useful life; that is, some insulation from the risk of obsolescence must be available. The most modern technology may be difficult to adapt, while a currently obsolete

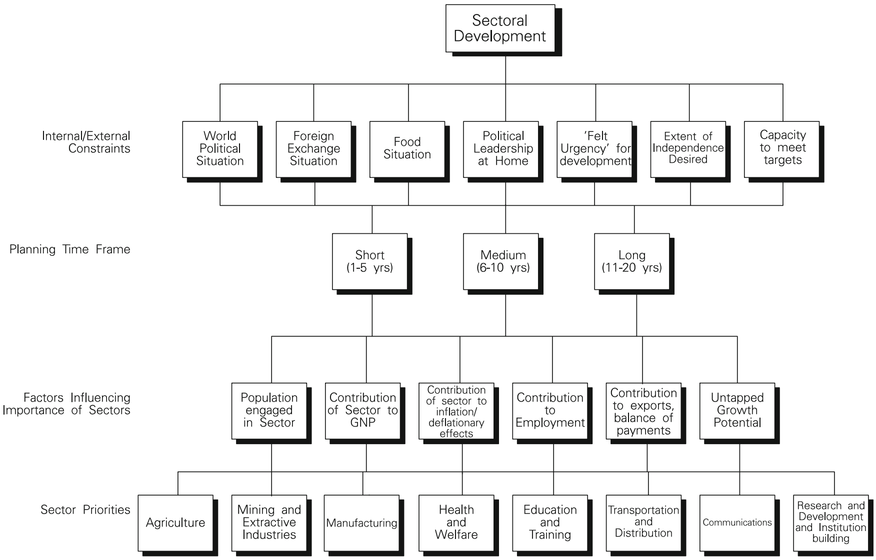


Fig. 9.2 Backward process hierarchy in technology assessment

technology may at a later date leave the LDC without adequate support. Thus a careful tradeoff has to be made as to the nature of the technology to acquire.

4. *No undesirable second-order consequences*: If the LDCs have any advantage as late comers in the process of technological development, it is the opportunity to profit from the lessons learned by the advanced countries as to the negative effects of certain types of technology. Impact analysis must be an integral part of any attempt to evaluate technologies for importation.

In general the needs for technology are influenced by sectoral priorities. Also, each of the preliminary assessment criteria listed above will be emphasized differently in the various economic sectors. For example, adaptability might be stressed in agriculture, which is a more traditional sector than manufacturing in most LDCs, whereas obsolescence risk might be underscored in manufacturing (see [11]).

Sectoral priorities may be taken as "given" if they are based on planning exercises done outside the context of technology assessment, a likely situation in many LDCs. However, the sectoral priorities themselves can be hierarchically determined. Two approaches are possible: a forward approach that starts with a level of national objectives and works down toward the desired sectoral priorities, and a backward approach that begins with constraints in both the internal and external environment of the LDC and converges on the feasible sectoral priorities, given the constraints (see [2]). Figure 9.2 illustrates the backward approach.

Returning to the problem of technology assessment (Fig. 9.3), we then have sector priorities at level 1, assessment criteria at level 2, and candidate

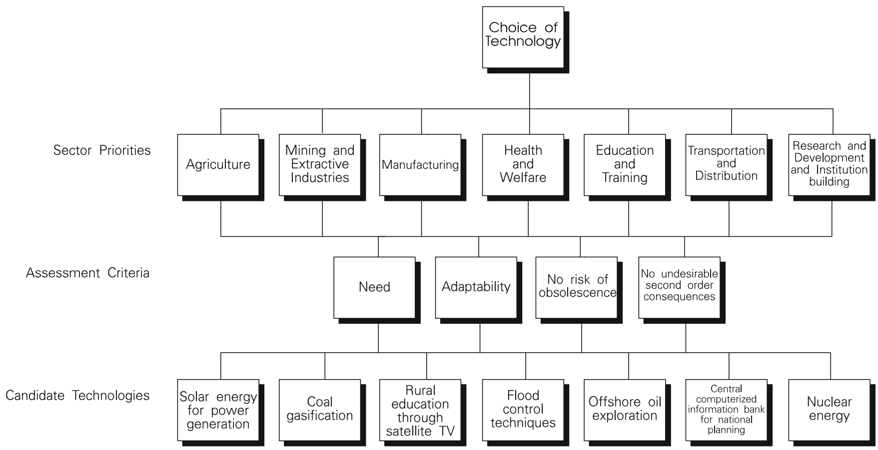


Fig. 9.3 Technology assessment hierarchy

technologies at level 3. Two assumptions are made in this particular construction of the hierarchy. First, technologies may or may not be sector-specific; some can be of general applicability, impacting many or all of the sectors—for example, transportation or communication technologies. Second, the importance of the assessment criteria varies across sectors, as mentioned earlier. Hence we prioritize the criteria by sector and weight the priorities of the criteria by sector weights to generate composite weighted criteria that can be applied uniformly to candidate technologies, after the technologies have been prioritized by criteria. A centralized technology evaluation organization would find this approach attractive from an administrative point of view and in the preparation of suitable guidelines.

To generate the criteria weights by sector, we pose, as before, a series of questions of the following type: for agricultural technologies (or manufacturing technologies, and so on), what is the relative importance of "need," "adaptability," "freedom from obsolescence risk," and "no undesirable second-order consequences"? This procedure entails pairwise comparison of each of the criteria with the others within a given sector.

It is thus possible to do a preliminary screening of many candidate technologies on the basis of the four key criteria and the sector weights of the country. This would result in a subset of the original list of candidate technologies that can be taken up for more detailed analysis.

9.3 An Example: Technology Transfer Using the AHP

In this example, which illustrates the approach described above, the sectoral priorities are taken as given and assumed to have been determined exogenously. In the context of a particular LDC, let us say the following are the sector priority weights:*

Agriculture	0.25
Mining and extractive industries	0.08
Health	0.12
Industry	0.15
Education and training	0.12
Communications	0.15
Transportation and distribution	0.06
Research and development	0.07

9.3.1 Prioritizing the Assessment Criteria with Sectors

As already discussed, the assessment criteria do not play the same role in all the sectors. They are prioritized within each sector in pairwise comparison matrices:

9.3.1.1 Agriculture

	(N)	(A)	(R)	(S)	Weight
Need (N)	1	1/3	7	5	0.292
Ease of adaptability (A)	3	1	9	7	0.587
No risk of obsolescence (R)	1/7	1/9	1	1	0.056
No undesirable Second-order consequences (S)	1/5	1/7	1	1	0.065

Consistency Index (C.I.) = 0.031

This matrix emphasizes that in the agricultural sector, the prime consideration for introducing an imported technology is adaptability. Risk of obsolescence and undesirable second-order consequences play relatively less important roles. These judgments, of course, are those of a particular analyst who provided the pairwise ratings shown in the matrix. Typically the entries of the matrix would be obtained after considerable debate and ultimate convergence by consensus among the members concerned.

9.3.1.2 Mining and Extractive Industries

	N	A	R	S	Weight
N	1	3	3	1	0.395
A	1/3	1	1	1/3	0.132
R	1/3	1	1	1	0.173
S	1	3	1	1	0.300

C.I. = 0.052

In the mining sector, in contrast to agriculture, need for the particular technology is felt to be the dominant criterion. “No undesirable second-order consequences” ranks second. Adaptability and risk of obsolescence are relatively less important, presumably owing to the state of development of this sector in the particular LDC.

9.3.1.3 Health

	N	A	R	S	Weight
N	1	1	3	7	0.402
A	1	1	3	7	0.402
R	1/3	1/3	1	3	0.143
S	1/7	1/7	1/3	1	0.057

C.I. = 0.002

The health needs of LDCs are widely different from those of the more advanced nations. Hence need and adaptability dominate here.

9.3.1.4 Industry

	N	A	R	S	Weights
N	1	1/3	1	1/3	0.132
A	3	1	3	1	0.395
R	1	1/3	1	1	0.173
S	3	1	1	1	0.300

C.I. = 0.050

The high weight assigned to adaptability and second-order consequences is self-explanatory in this sector. Whereas in agriculture the problem of adaptability may be related to the ability or willingness to adapt, in manufacturing there may be infrastructural barriers to adaptation, such as lack of skilled manpower, local suppliers of spare parts, repair facilities, and the like. The size of the market might dictate scaled-down plants, which could create operating problems.

9.3.1.5 Education and Training

	N	A	R	S	Weight
N	1	5	9	3	0.587
A	1/5	1	5	1	0.172
R	1/9	1/5	1	1/5	0.044
S	1/3	1	5	1	0.196

C.I. = 0.033

The need for the particular type of educational technology is important, but education that raises levels of aspiration can be dysfunctional if there are no simultaneous increases in available opportunities. Hence a high score is obtained on undesirable consequences of rapid education.

9.3.1.6 Communications

	N	A	R	S	Weight
N	1	5	1/5	1	0.169
A	1/5	1	1/7	1	0.047
R	5	7	1	5	0.615
S	1	1	1/5	1	0.169

C.I. = 0.070

Modern communications technologies are characterized by high obsolescence risk. LDC concern with obsolescence risk is reflected by the high weight attached to that factor in this sector. Criteria weights in the remaining sectors are obtained similarly.

9.3.1.7 Transportation and Distribution

	N	A	R	S	Weight
N	1	1/3	1/5	1	0.096
A	3	1	1/3	3	0.249
R	5	3	1	5	0.558
S	1	1/3	1/5	1	0.096

C.I. = 0.020

9.3.1.8 R&D and Institution Building

	N	A	R	S	Weight
N	1	5	1	3	0.397
A	1/5	1	1/5	1	0.090
R	1	5	1	3	0.397
S	1/3	1	1/3	1	0.116

C.I. = 0.010

Now these sector-based criteria weights are adjusted by the sector priorities to get the overall criteria weights for the particular LDC:*

Need	0.302
Ease of adaptability	0.314
No risk of obsolescence	0.230
No undesirable second-order consequences	0.154

9.3.2 *Assessment of Candidate Technologies*

It is now possible to apply these overall weights to candidate technologies. Let us assume that this LDC is considering adapting the following seven candidate technologies (all "mass" technologies, some of which have direct and potential impacts in many sectors):

1. Solar energy development (SOL) for rural power and irrigation;
2. Coal gasification plants (CG) to utilize an abundantly available natural mineral resource;
3. Satellite television for extending primary and secondary education to the rural areas (RUR);
4. Flood control techniques (FC) to avoid massive national losses due to floods;
5. Offshore oil exploration (OIL) to minimize dependence on foreign oil;
6. A computerized national information bank (COMP) to facilitate national and state-level planning;
7. Nuclear energy (NUCL) for electricity generation.

These technologies are now compared to each other with respect to each of the assessment criteria. Application of the pairwise comparison procedure yields the following weights with regard to *need* for the different candidate technologies:

9.3.2.1 Need

	SOL	CG	RUR	FC	OIL	COMP	NUCL
Weight:	0.112	0.027	0.341	0.179	0.258	0.058	0.024

C.I. = 0.18

In the opinion of the analyst who provided the judgments in this matrix, rural education (a long-term, low-risk project) and oil exploration (a short-to-medium term, high-risk project) are the major national needs. Flood control and solar energy are believed to be the next most important technologies from the point of view of addressing national needs most directly. The consistency index of 0.18 is rather high, even for a 7 × 7 judgment matrix. To some extent this happens because of the broad types of comparison involved. In real life, one would be more specific by clustering technologies so that they are more comparable.

Next, with respect to *ease of adaptability*, the relative standing of the candidate technologies is as follows:

9.3.2.2 Ease of Adaptability

	SOL	CG	RUR	FC	OIL	COMP	NUCL
Weight:	0.381	0.054	0.263	0.158	0.034	0.021	0.090

C.I. = 0.13

Solar energy technology is believed by the analyst to be most easily adaptable, followed by rural education through satellite television, and then by flood control. Nuclear energy, being more automated, scores higher on adaptability, whereas the need for trained and skilled personnel is higher for both coal gasification and oil exploration technologies, which makes them more difficult to adapt.

With respect to no risk of obsolescence, the relative standing of the candidate technologies is as follows:

9.3.2.3 No Risk of Obsolecence

	SOL	CG	RUR	FC	OIL	COMP	NUCL
Weight:	0.155	0.030	0.135	0.357	0.058	0.097	0.168

C.I. = 0.20

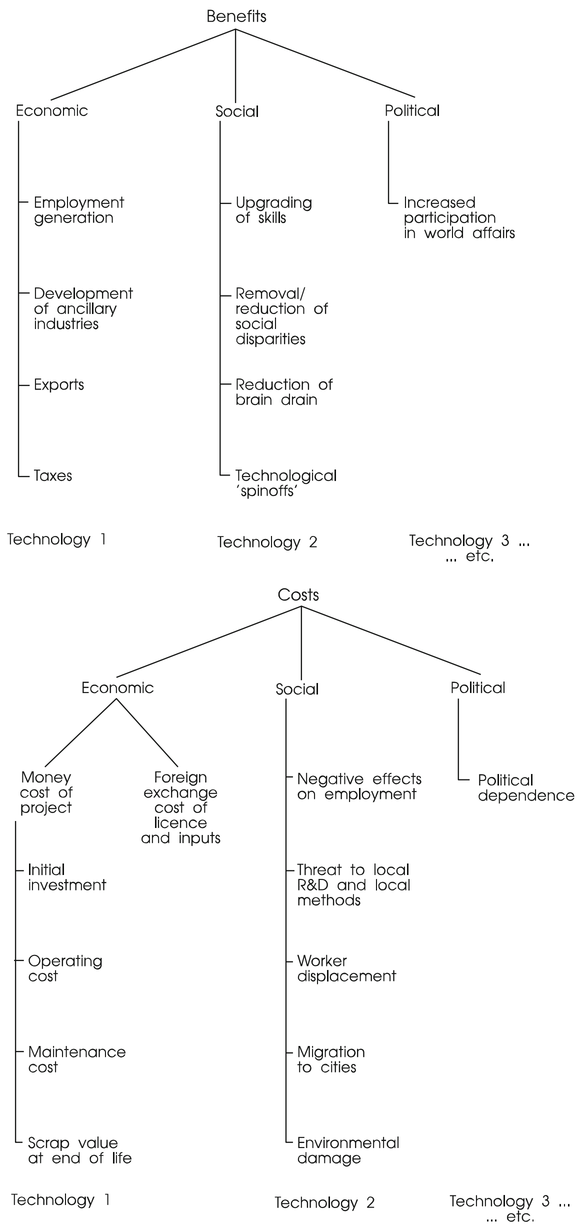
Finally, the criterion of *no undesirable second-order consequences* led to the following prioritization:

	SOL	CG	RUR	FC	OIL	COMP	NUCL
Weight:	0.457	0.043	0.172	0.167	0.043	0.099	0.018

C.I. = 0.11

The weights obtained for each technology under each criterion are then weighted by the criteria weights and summed to get the overall technology weights:

Fig. 9.4 Benefits and costs hierarchies



The overall weighted priorities suggest that solar energy should receive maximum emphasis, followed by satellite television, flood control, oil exploration, nuclear energy, computerized information bank, and coal gasification, in that order. The high weight for solar energy is principally due to the high weight it

Solar energy	0.259
Coal gasification	0.039
Rural education	0.243
Flood control	0.211
Oil exploration	0.109
Computerized information bank	0.062
Nuclear energy	0.077

obtains with respect to ease of adaptability to a rural economy and the absence of any conceivable second-order consequences associated with this technology.

Despite the high need for satellite television for rural education, it is perceived by the analyst to be a potentially dysfunctional technology in the sense of distracting the masses rather than really educating them. Similarly the high need score for oil exploration is counterbalanced by problems in adapting the technology to local situations, obsolescence risk, and possible second-order consequences like pollution of the coastal area. Nuclear energy gains on account of its relatively easy adaptability and the fact that the technology is a rather stable one less prone to obsolescence.

It is clear from this example that the AHP permits quantification of the relative priorities of various technological options. The rankings obtained here reflect the values, opinions, and judgments of a particular rater. But if the prioritization is done in a group setting, then debate can be generated and judgments made on the basis of consensus. The purpose of the example is to illustrate the application of the AHP rather than to suggest any particular prioritization of technologies for any particular LDC.

After the potentially most useful or desirable technologies are identified on the basis of the four key criteria, conventional approaches such as cost/benefit analysis can then be used to select from among the candidate technologies.

Figure 9.4 suggests a cost/benefit approach using the AHP. We construct separate cost and benefit hierarchies and use the final cost and benefit weights to derive cost/benefit ratios for the technologies under consideration. Thus we obtain an ordering of the technologies in terms of their cost/benefit ratios.

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Chapter 10
Market Attractiveness of Developing Countries

10.1 Introduction

Companies operating in international markets need to evaluate the potential market attractiveness of developing countries with which they may want to do business. These companies have access to substantial amounts of information from specialized sources and from statistical data supplied by international institutions. Such vast and diverse information is rarely used in a systematic way in the management decision process. When it is used, the entire process is most often inadequately formalized. The available information generally deals with economic factors, while in the present international arena, judgment about politics must also be taken into account. This chapter illustrates the applicability and advantages of the Analytic Hierarchy Process to this decision problem, and uses it to create maps of joint economic progress and political stability in a number of countries for two time periods 1990–1991 and 1995–1997.

A salient business phenomenon in the past 10 years has been the "globalization" of economic and industrial activity. Production is spreading throughout the world in pursuit of economic and labor advantages. These advantages offer greater flexibility in maintaining quality, lowering costs and improving competitiveness. In addition, the type of government running a country and its political outlook affect the internal administration and the international image of that country which could encourage or deter companies from seeking business there.

Companies operating in the international environment, who analyze the market of developing countries to determine their own actions, often only consider specific factors such as the supply of raw materials, infrastructure requirements, demand on the goods, and the exploitation of attractive production factors. Nowadays they must consider the international situation as a macroenvironment in which economic, financial and political factors create new conditions. These conditions, directly and indirectly, could represent threats or opportunities to business. The need for a thorough analysis of the macroenvironment is stressed in

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the Strategic Management literature which is growing in importance with its own approaches. Such names as "External Audit" and "External Factor Evaluation" [2] are being used to classify the environment. To model the discontinuity in the present situation, the scenario approach has been used [7].

The authors' company, Iritecna, has manufacturing activities in the general engineering industry which include steel and non-ferrous metallurgy, logistic activities for industrial plants and transport systems, and various involvements in public utility infrastructures. It has locations in Latin America, North Africa, Eastern Europe, the Middle and Far East. Its relationship to the world market is not a simple transaction oriented buying-selling relationship. Rather, the relationship with partners places emphasis on: (1) the quantity of money involved (about $1,000,000 U.S.) and the significance of the length of a contract (preferably more than 1 year); (2) the complexity of the rules of payment; and (3) the presence of the company as a shareholder in some business activity.

The broad spectrum of industry segments in which the company operates as well as its close involvement with the host country required by the particular way of doing each type of business has suggested to the Planning Department the need for an ongoing activity to monitor prevalent political and economic-financial trends in the countries where it operates. In order of decreasing importance, the goals of this undertaking are to create a process through a study and resulting report that:

- incorporates and correctly addresses the use of information, standard scale data, ratings, and subjective judgments arising from different sources,
- supports and enhances the process of resource allocation for promotional and commercial purposes,
- suggests new opportunities not well perceived by the company because of its strong involvement in existing business activities,
- develops a final report containing a graded map with (cartographic) characteristics, a kind of tactical board which portrays activity countries positioned according to their socio-economic and political movements that influence the macro-factors,
- makes possible learning about the future of the macroenvironment in which the company operates,
- stimulates team discussion about the problem of where to go and when to go, and utilizes expert knowledge and judgment for that purpose.

The last three goals clarify the intention to start a "macroenvironment modelling activity" that enables involvement and utilization of the creativity and judgment of both analysts and managers. Reports usually do not conform with an ongoing modelling process, but must be examined item by item. The specialized literature [2] suggests the use of weighted scoring methods to summarize and evaluate information relating to "macroenvironmental analysis." Multicriteria methodologies such as Electre [9] specify a process to scale data and evaluate a final alternative to follow for each decision. But these methods do not satisfy the need for a flexible framework to represent an ongoing process of decision making. Multivariate statistical methods, used as geometric representations supporting Multiple Criteria

Decision Making processes [3], were tested. It was difficult to interpret the final outcome as a map of the environment because of its dependence on the measurable statistical properties of the data rather than on the perception of the problem with its social and political ramifications as they apply to each country.

The AHP [11] appeared to be well suited mainly for the richness of its frame (hierarchical arrangement of the factors) which permits one to give evidence of how the problem is perceived. It also allows for the use of intangible factors side by side with tangible ones. It uses a simple procedure of paired comparisons to elicit judgments from which it derives ratio scales. It then combines these ratio scales to derive an overall ratio scale for the decision. Guided by a number of applications of the AHP in the socio-economic planning field, it was decided to use it in making this type of decision to: a) structure and map the problem in the economic and political dimensions; b) interpret and use the results for decision purposes.

10.2 Representation of the Problem

The market attractiveness of a country is perceived to be related to two sets of factors deriving from two points of view: economic and financial, and political. Explicit mention of politics stems from the need for specifying factors that are in general included but not completely measured, by some of the financial indicators of risk. The economic-financial factors considered here are:

1. *Growth rate of Gross Domestic Product* (*GDP*), to give evidence about the economic forces of the country.
2. *GDP per Person*, to monitor the present richness of the country. The assumption “per” person is a cover up for concentrated isles of richness in a developing country.
3. *Inflation rate*, is an indicator of stability in managing exchange rate leverage and of potential future development.
4. *Current account over GDP*, is an indicator of a country‘s proneness to invest.
5. *Risk of direct investment*, is a way to monitor the credit worthiness of a country.

The political factors are:

6. *Turmoil*, relating to the level of sociopolitical conflict within the country.
7. *Strategic Relevance*, is an indicator of a country‘s geographic and historical importance.

Following the AHP approach, this portion of the problem is modelled as shown in the top portion of Fig. 10.1. Two important comments need to be made regarding the structure of the model.

First, the “economic-financial” node of the first level could be further subdivided into “economic” and “financial” and placed at the second level of the hierarchy. The five factors described above would then be positioned in the third level of the hierarchy and linked to the parent node to which they belong.

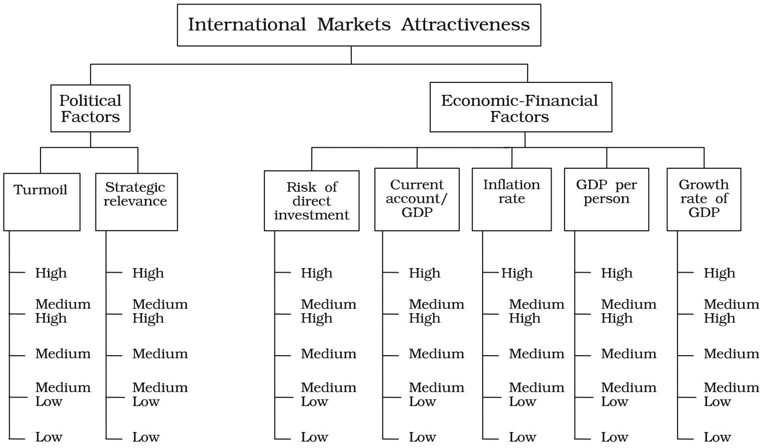


Fig. 10.1 Hierarchical structure

Second, the "strategic relevance" node could be decomposed into four sibling nodes; underground resources, geographic position, historical importance, and power sharing.

These nodes have not been included in the present version because our aim has been to remain "simple" and relevant. We would also have encountered the difficulty of finding more specific data on them.

The third level of the model contains rating intensities by which the second level criteria are measured: High, Medium High, Medium, Medium Low, and Low.

Where quantitative information is available, a relationship between rating intensities and measurement data is used to make the evaluation (See Table 10.1). All evaluations are ordered to give less desirable traits a lower rating. For example, heavy turmoil, significant inflation and considerable risk for investment are all given low ratings.

A country is evaluated for its "performance" with respect to each second level criterion using the most appropriate rating grade to describe it. These results are weighted and combined to yield weights with respect to the two major criteria. A map of market potential displaying the synthesized results is the output sought.

10.3 Priorities

The AHP methodology requires priorities for each level of criteria and for each rating intensity. These priorities are always determined in terms of their parent node in the hierarchy. Relative value is derived from pairwise comparisons. Judgments can be made directly with numerical scales or with a semantic scale translated to numbers. For example, within the "Political" factors, the "Turmoil" subcriterion is strongly more important than "Strategic relevance" (scale value 5). This strength of dominance is assigned for two reasons.

Table 10.1 Relation between rating grades and measurement data

Sub-criteria	High	Medium–High	Medium	Medium–Low	Low
Turmoil	Consolidated and stable democracy or stable dictatorship. Absence of social tension	Democracy not fully consolidated or dictatorship with initial signs of opposition and of social tension	Very recent democracy with political power not consolidated. Spreading social conflict.	Strong opposition outside the democratic process. Presence of guerillas. Bad social conditions	Political anarchy and ugly social conditions
Strategic performance	Richness of raw materials. Key role for power sharing in the area. Bridge between two different areas. Historical relevance in the area		Presence of some raw materials. Partnership in regional alliances. Active role in international negotiation processes		Absence of raw materials. Marginal role (political, ideological and historical) in the area
Risk of direct investment	Time reference 1990–1991: (ref. Institutional Investors) in the top list of Credit Country ratings 1991. Time reference 1995–1997: (ref. Planning Review) Risk Rating for direct investment A+, A	Time reference 1995–1997: (ref. Planning Review) Risk Rating of direct Investment A−, B+, B	Time reference 1990–1991: (ref. Institutional Investors) In median position of the list of Credit Country rating 1991. Time reference 1995–1997: (ref. Planning Review) Risk rating for direct investment B−, C+, C	Time reference 1995–1997: (ref. Planning Review) Risk Rating for direct investment C−, D+	Time reference 1990–1991: (ref. Institutional Investors) At the bottom of the list of Credit Country rating 1991. Time reference 1995–1997: (ref. Planning Review) Risk for direct investment D, D−
Current account/GDP	>3%	$3\% \gg 1\%$	$1\% \gg 0\%$	$0\% \gg -2\%$	−2% >
Inflation Rate	<2%	$2\% \ll 4\%$	$4\% \ll 7\%$	$7\% \ll 10\%$	10% <
GDP per capita	>5000$	5000$ ≫3000$	3000$ ≫1500$	1500$ ≫ 500$	500$ >
Growth rate of GDP	>4%	$4\% \gg 3\%$	$3\% \gg 2\%$	$2\% \gg 1\%$	1% >

Table 10.2 Pairwise comparison matrix components of the financial economic criteria

	Risk of direct investment	Current account/ GDP	Inflation rate	GDP per person	Growth rate of GDP	Priorities
Risk of direct investment	1	6	3	3	1	0.353
Current account/ GDP		1	1/2	1/1	1/6	0.058
Inflation rate			1	1	1/3	0.118
GDP pro capite				1	1/3	0.118
Growth rate of GDP					1	0.353

First present conditions are more relevant and pressing than long term and uncertain evidence, and secondly, for "Turmoil" there is a significant amount of information supplied by the specialized press and/or ratings institutes, while the importance of "Strategic relevance" requires expert knowledge.

Evaluation of the elements under "Economic and financial" factors appears in Table 10.2.

The resulting priorities show that:

- "Risk of Direct Investment" and "GDP Growth" are equally important and together these two criteria dominate the remaining criteria.
- "Inflation Rate" and "GDP per Person" are next in priority and are significantly less important than the previous two.
- "Balance Account/GDP" has the lowest priority.

These results mean that in order for a country to be attractive it should be in the expansion phase and present low risk.

The AHP proved useful in creating intensity ratings for the next stage because for most of the criteria there were no data for rating the alternatives and one had to resort to the use of judgments. The resulting priorities are related to the relevance given to the scale. For example, "Risk of Direct Investment" had no economic indicator to evaluate the countries. Therefore, we had to create a scale of relative intensities for the criteria and then used that to rate the countries. Here we did not have the means to conduct and combine diverse analyses and to produce a numerical outcome to be used in the model.

The pairwise comparison matrices for the five rating grades under each second level criterion appear in Table 10.3a–g. The local priorities represent the relative importance of a particular rating with respect to the parent criterion. It should be noted that the differences in priorities decrease as one moves from the two highest rating grades (High and Medium High) to the two lowest ones (Medium Low and Low) for nearly all seven second level criteria. Exceptions are "Risk of Direct Investment" and "Inflation Rate" for which it appears more correct that there should be significant change from Medium High to Medium.

Table 10.3 Pairwise comparison matrix for the rating grades

(a) turmoil

	High	Medium high	Medium	Medium low	Low	Priorities
High	1	1.5	3	5	7	0.429
Medium–high		1	1.5	3	5	0.268
Medium			1	1.5	3	0.156
Medium–low				1	1.5	0.091
Low					1	0.057

(b) Strategic relevance

	High	Medium high	Medium	Medium low	Low	Priorities
High	1	1.5	3	5	7	0.429
Medium–high		1	1.5	3	5	0.268
Medium			1	1.5	3	0.156
Medium–low				1	1.5	0.091
Low					1	0.057

(c) Risk of direct Investment

	High	Medium high	Medium	Medium low	Low	Priorities
High	1	1.5	3	5	9	0.409
Medium–high		1	1.8	4	9	0.295
Medium			1	2.5	7	0.117
Medium–low				1	5	0.09
Low					1	0.029

(d) Balance account/GDP

	>3% H	3% ≫ 1% M H	1% ≫ 0% M	0% ≫ −2% M L	−2% > L	Priorities
>3% H	1	2	4	7	9	0.460
3% ≫ 1% M H		1	3	5	8	0.299

(continued)

Table 10.3 (continued)

(d) Balance account/GDP

	>3% H	3% ≫ 1% M H	1% ≫ 0% M	0% ≫ −2% M L	−2% > L	Priorities
1% ≫ 0% M			1	3	6	0.144
0% ≫ −2% M L				1	3	0.065
−2% > L					1	0.032

(e) Inflation rate

	<2% H	2% ≪ 4% M H	4% ≪ 7% M	7% ≪ 10% M L	10% < L	Priorities
<2% H	1	1.5	3	6	9	0.409
2% ≪ 4% M H		1	3	5	7	0.324
4% ≪ 7% M			1	3	6	0.159
7% ≪ 10% M L				1	4	0.076
10% < L					1	0.033

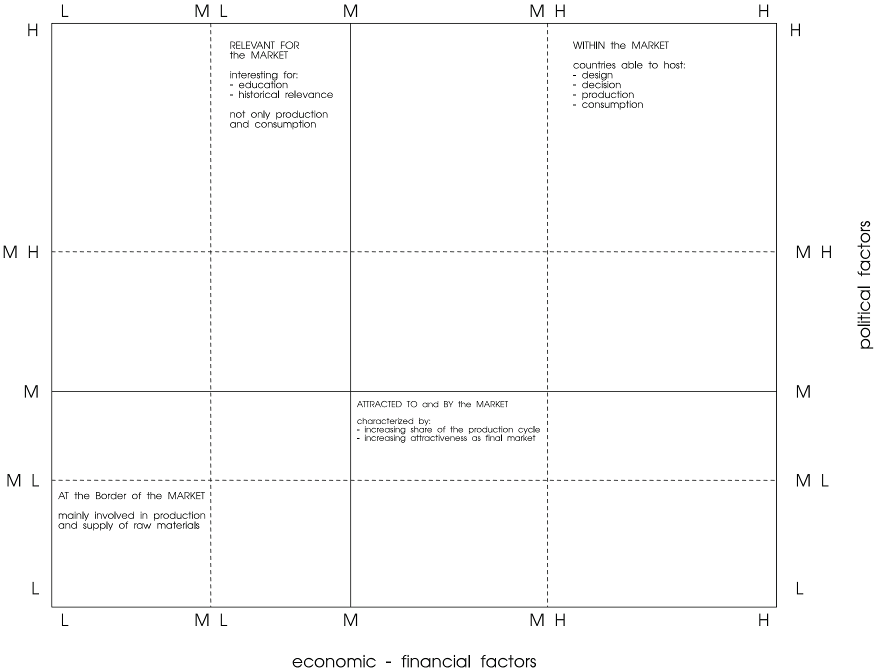
(f) GDP per person

	>5000$ H	5000$ ≫ 3000M H	3000$ ≫ 1500M	1500$ ≫ 500% M L	500$ > L	Priorities
>5000$ H	1	2	4	7	9	0.460
5000$ ≫ 3000M H		1	3	5	8	0.299
3000$ ≫ 1500M			1	3	6	0.144
1500$ ≫ 500M L				1	3	0.065
500$ > L					1	0.032

(g) Growth rate of GDP

	>4% H	4% ≫ 3% M H	3% ≫ 2% M	2% ≫ 1% M L	1% >L	Priorities
>4% H	1	1.5	2.5	5	9	0.460
4% ≫ 3% M H		1	1.5	3	9	0.299
3% ≫ 2% M			1	2	7	0.144
2% ≫ 1% M L				1	7	0.065
1% > L					1	0.032

Table 10.4 Basic map for countries positioning



Two axes were chosen to represent "Political" and "Economic and Financial" criteria. The five rating intensities are positioned along each axis in increasing priority order. In synthesizing the local priorities established above, the rating scales can be grouped into four segments with respect to each of the two major criteria (see Table 10.4). The result is that the intersection of the two groupings leads to a division of each segment of one into four subsegments.

Each of the segments and subsegments has a unique size. Here the AHP analysis offers a different approach than the commonly used procedure called the Boston Consulting Group matrix representation. Segment uniqueness is a feature provided by the AHP to more accurately set the values of the five rating intensities which is not possible in other methods known to us. Table 10.4 portrays an interpretation of the four major segments in terms of overall market attractiveness.

10.4 Country Ratings

Countries examined in the study fall in six geographical regions:

- Latin America
- Mediterranean Africa
- Middle East

- Eastern Europe
- Indian Subcontinent, and
- Far East

For historical reasons, the first four regions represent the reference market for Italian companies exporting industrial plants and infrastructures. The last two are included because in the last decade they have come to represent growing opportunities for Italian exports. There are also other reasons than historical ones that necessitate tracing countries according to recent trends, to attract some of them into influence zones, whose leaders are:

- U.S.A.;
- E.E.C.;
- Japan.

The countries included in this analysis (see Table 10.5) are the more important ones in each region. They belong to the well known category of Developing or Newly Industrialized Countries. Some relevant countries which one might expect to find in Table 10.5, are missing mostly because of lack of complete data and/or because they are in the process of splitting into sovereign states. South Africa and Nigeria, which do not belong to the geographical regions mentioned above, are included for their relevance to Italian companies. The country list reflects the fact that the company originating the study is based in Italy and is dependent on its government's political and cultural relationship with other nations. Had the company been French instead of Italian, the list could have been different, including some countries in Central Africa.

The model evaluates each country under each of the seven second level criteria. The evaluation is made by assigning the most appropriate rating intensity to a country's "performance" in each of the "performance" categories. The most appropriate rating intensity is determined by the best available quantitative and qualitative information. The study considers two time reference periods: 1990–1991 and 1995–1997 (Table 10.6).

The sources of financial and economic information for each of the reference periods are the following:

Period 1990–1991

- "Risk of Direct Investment" is based on rating data [1];
- "Current Account/GDP" is based on data from the "World Bank Annual Report";
- "Inflation Rate" is based on the annual report on risk forecast published by Planning Review;
- "GDP per Person" was derived using data relating GDP and Population [12];
- "GDP Growth" is based on data from the annual report of Planning Review.

Period 1995–1997

- "Risk of Direct Investment" is based on rating data of the annual report of Planning Review;

Table 10.5 Country ratings 1990–1991

Time reference 1990/1991	Political factors		Economic-financial factors						
Local priorities	Turmoil 83%	Strategic relevance 17%	Risk of direct investment 35%	Currect account/ GDP 6%	Inflation rate 12%	GDP per person 12%	Growth rate of GDP 35%	Political evaluation	Economic financial evaluation
Algeria	M	MH	M	L	L	M	M	40.8	35.8
Argentina	M	M	M	ML	L	H	M	36.5	32.6
Bangladesh	M	ML	L	L	M	L	L	33.9	11.0
Bolivia	ML	L	L	L	L	ML	M	19.8	21.5
Brazil	M	M	ML	M	L	ML	L	36.5	16.9
Bulgaria	M	L	L	ML	L	ML	L	32.4	8.9
Chile	M	L	M	L	L	MH	H	32.6	57.9
China	MH	MH	MH	ML	ML	L	H	62.5	63.2
Colombia	ML	ML	ML	M	L	ML	H	21.2	46.8
Cuba	H	MH	L	ML	ML	ML	ML	93.8	17.0
Ecuador	ML	ML	L	L	L	ML	ML	21.2	15.3
Egypt	M	MH	ML	L	L	ML	H	40.6	45.2
Hong Kong	H	MH	H	ML	ML	H	H	93.8	85.1
Hungary	M	M	MH	L	L	MH	L	36.5	36.1
India	M	M	MH	L	ML	L	H	36.5	62.7
Indonesia	ML	M	MH	ML	ML	ML	H	23.7	64.1
Iran	ML	MH	ML	ML	ML	L	MH	40.8	34.9
Iraq	H	MH	M	ML	M	M	ML	28.1	30.1
Malaysia	M	M	H	ML	MH	M	H	89.4	62.6
Mexico	MH	M	M	L	L	MH	M	58.2	38.3
Morocco	M	M	ML	L	M	ML	MH	36.5	37.7
Nigeria	ML	M	L	ML	L	L	H	23.7	39.6
Pakistan	ML	M	ML	L	ML	L	H	23.7	45.5

(continued)

Table 10.5 (continued)

Time reference 1990/1991	Political factors		Economic-financial factors						
Local priorities	Turmoil 83%	Strategic relevance 17%	Risk of direct investment 35%	Currect account/ GDP 6%	Inflation rate 12%	GDP per person 12%	Growth rate of GDP 35%	Political evaluation	Economic financial evaluation
Peru	ML	ML	L	MH	M	ML	L	21.2	15.6
Philippines	ML	M	ML	L	ML	ML	H	23.7	46.4
Poland	M	M	ML	L	L	M	L	36.5	15.4
Russia	M	MH	M	ML	L	ML	L	40.8	21.3
Saudi Arabia	H	H	H	L	MH	H	MH	100.0	80.5
Singapore	MH	M	H	H	MH	H	H	58.2	97.6
South Africa	MH	H	M	MH	L	MH	ML	68.8	36.8
South Korea	MH	MH	H	MH	M	H	H	82.5	90.7
Syria	MH	MH	L	M	L	ML	H	62.5	41.6
Taiwan	H	M	H	H	MH	H	H	89.4	97.6
Thailand	M	MH	H	L	M	M	H	40.8	77.5
Turkey	M	H	MH	M	L	M	H	47.1	65.9
Venezuela	M	M	M	H	L	M	MH	36.5	49.3
Vietnam	H	M	L	ML	L	L	MH	89.4	29.5

Table 10.6 Country ratings 1995–1997

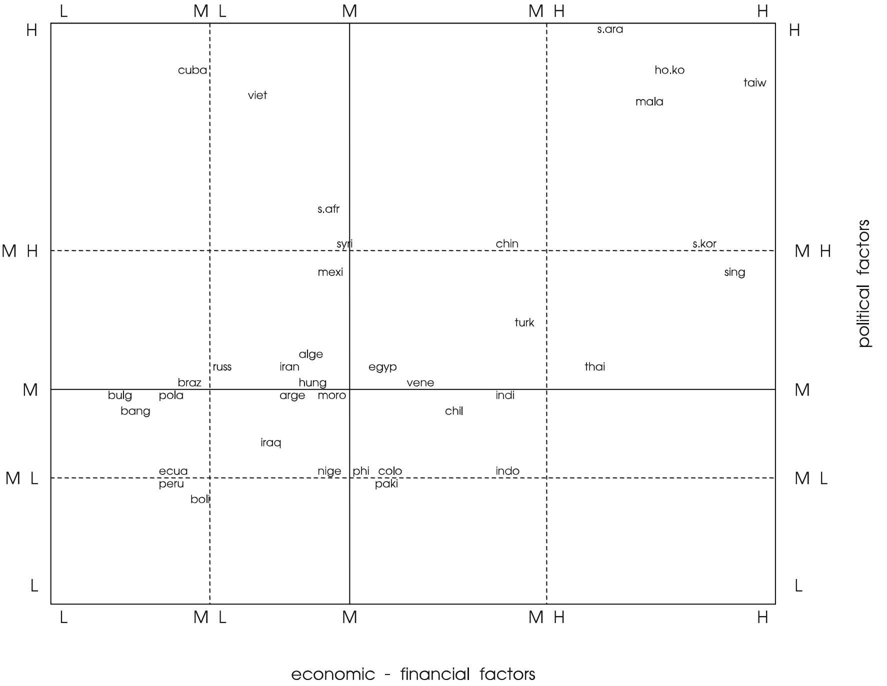
Time reference 1990/1997	Political factors		Economic-financial factors						
Local priorities	Turmoil 83%	Strategic relevance 17%	Risk direct investment 35%	Currect account GDP 6%	Inflation rate 12%	GDP person 12%	Growth rate GDP 35%	Political evaluation	Economic financial evaluation
Algeri	M	M	ML	L	L	M	H	23.7	47.1
Argentin	M	M	M	ML	L	H	H	36.5	64.3
Banglades	M	ML	L	L	M	L	ML	33.9	18.0
Bolivi	ML	L	L	L	L	ML	M	19.8	21.5
Brazi	M	M	ML	M	L	M	M	36.5	30.1
Bulgari	M	L	M	L	L	MH	H	32.6	22.1
Chil	M	L	M	L	L	MH	H	32.6	57.9
Chin	MH	MH	M	M	ML	L	H	62.5	64.3
Colombi	ML	ML	L	M	L	ML	H	21.2	41.6
Cub	MH	M	ML	ML	M	ML	ML	58.2	24.5
Ecuado	ML	ML	L	L	L	ML	M	21.2	21.5
Egypt	m	M	L	ML	L	ML	M	36.5	21.9
Hong	MH	H	MH	MH	ML	H	H	68.8	78.7
Hungar	MH	ML	MH	MH	L	MH	M	55.6	53.0
Indi	M	MH	M	L	ML	ML	H	40.8	52.6
Indonesi	ML	M	M	ML	ML	ML	H	23.7	54.2
Ira	M	MH	ML	M	ML	L	H	40.8	46.8
Ira	M	M	L	ML	L	M	ML	36.5	17.7
Malaysia	H	M	MH	L	M	MH	H	89.4	71.4
Mexic	MH	M	MH	L	L	MH	H	58.2	67.8
Morocc	M	M	ML	L	M	ML	MH	36.5	37.7
Nigeri	ML	M	L	M	L	L	MH	23.7	37.7
Pakistan	ML	M	L	L	L	L	H	23.7	29.6

(continued)

Table 10.6 (continued)

Time reference 1990/1997	Political factors		Economic-financial factors						
Local priorities	Turmoil 83%	Strategic relevance 17%	Risk direct investment 35%	Currect account GDP 6%	Inflation rate 12%	GDP person 12%	Growth rate GDP 35%	Political evaluation	Economic financial evaluation
Per	ML	ML	L	L	L	ML	ML	21.2	15.3
Philippine	ML	M	L	L	L	ML	MH	23.7	29.0
Polan	M	M	M	ML	L	M	ML	36.5	30.1
Russi	M	H	M	ML	L	ML	ML	47.1	28.3
Saudi	H	H	MH	L	M	H	H	100.0	77.3.
Singapor	H	M	H	MH	MH	H	H	89.4	95.3
South	M	H	L	M	L	MH	MH	47.1	35.9
South	MH	H	H	MH	ML	H	H	58.2	85.1
Syri	MH	MH	L	M	L	ML	M	62.5	23.0
Taiwa	H	M	H	H	MH	H	H	89.4	97.6
Thailan	MH	MH	H	L	M	M	H	62.5	77.5
Turke	M	MH	MH	M	L	M	H	40.8	65.9
Venezuel	M	M	M	H	L	MH	H	36.5	63.9
Vietna	H	M	L	ML	L	L	H	89.4	39.6

Table 10.7 Map—reference period 1990–1991



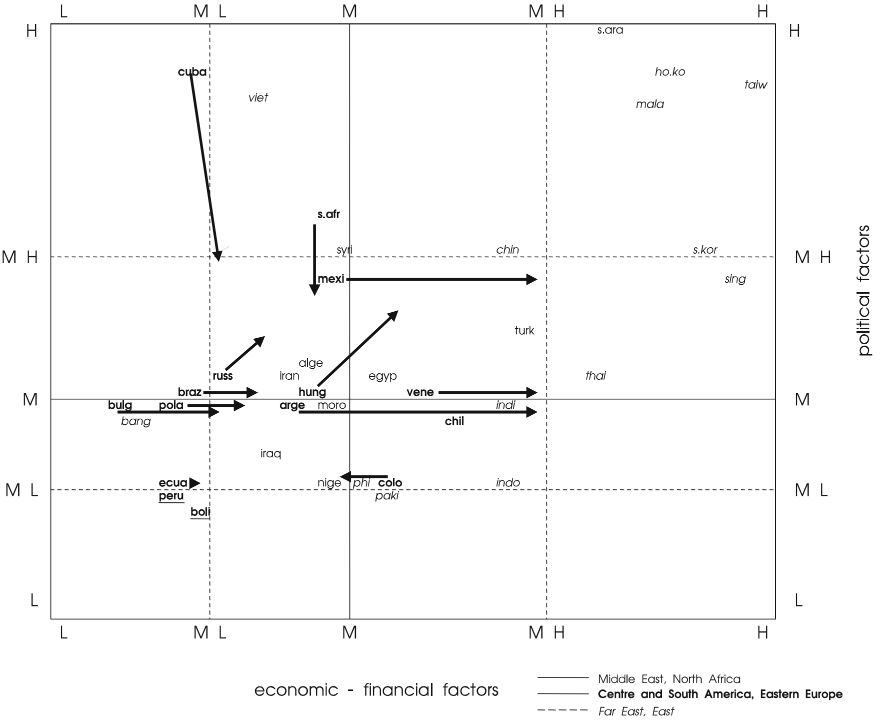
- "Current Account/GDP" is derived from the annual report of Planning Review (Current Account) and on World Bank Report data (forecast of GDP value);
- "Inflation Rate" is based on the annual report on risk forecast published by Planning Review;
- "GDP per Person" was derived using data relating GDP and Population of the World Bank Annual Report;
- "GDP Growth" is based on data of the annual report of Planning Review.

For the two reference periods, the country ratings for the two subcriteria of the political criterion are based on the annual report of Planning Review for "Turmoil" and on subjective judgments for "Strategic Relevance".

10.5 Positions of Countries

Based on the rating data of the countries, a market attractiveness map is developed in Table 10.4. The priority distribution of countries for the 1990–1991 time period appears in Table 10.7. Table 10.8 represents the change in priorities of the countries from the first to the second time period according to region. Table 10.9 shows the priority distribution of the countries for the 1995–1997 time period.

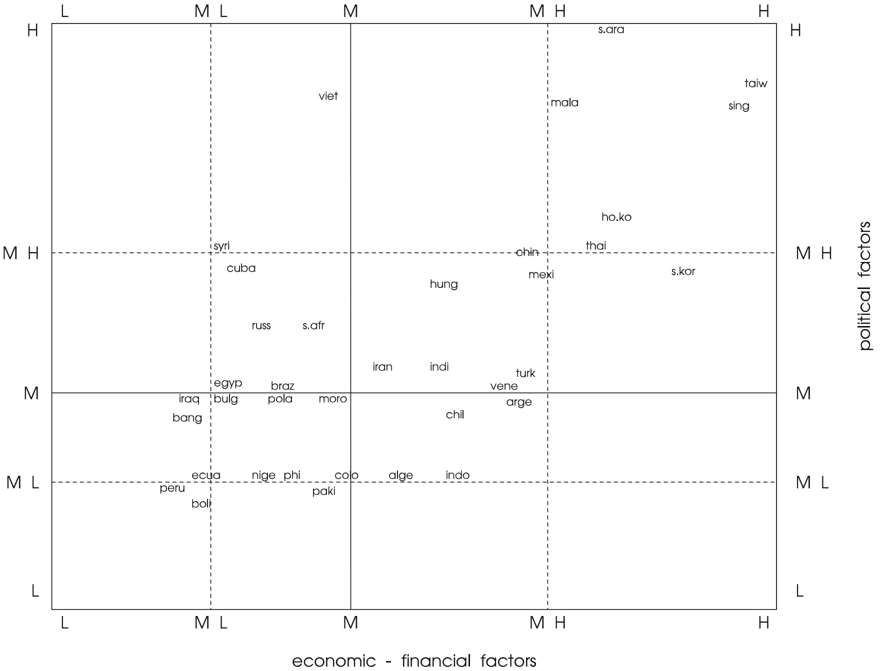
Table 10.8 Shifting in countries map position reference time period 1990–1991



The final maps suggest the following ideas:

- Most countries fall along a diagonal starting from the lowest point (L–L) to the highest one (H–H) on both main criteria. This indicates that there is a possible correlation between the economic-financial and the political factors;
- The highest subquadrant (MH–MH, H–H) contains the Far Eastern Countries. The accuracy of this outcome is commonly supported by reports made in literature specializing in political and economic trends [6]. The Far East could be the one area in which newcomer countries are entering in a continental area market. This fact is perceived by commentators to be one of the major competitive advantages of Japan who is succeeding (where Europe and the USA have problems) in creating a market development area. The position of Malaysia and Hong Kong is worsening due to a decrease in their rating on Risk of Direct Investment. China is moving toward this subquadrant slowly but very significantly. Saudi Arabia is also included in this subquadrant, but its uniqueness (no other significant country of the area is as close a position on the map) indicates a possible long term instability.
- In the second highest subquadrant (M–M, MH–MH), there are countries that appear to shift their position on the map between the two reference periods. Turkey, perceived to be an interesting newcomer [10], shows a stable

Table 10.9 Map—reference period 1995–1997



economic-financial position. It is a country moving west by requesting EEC membership, and east toward the ex-USSR republics with Turkish languages. Hungary and Mexico are entering this subquadrant, both being close to other continental markets (the European and the North American). Mexico and other Latin American countries (notably Argentina) are also moving close to this subquadrant. This is an indication of significant movements in the American continent whose central core is NAFTA (North American Free Trade Agreement), represented in the literature [4] as a possible strategic initiative to counter the EEC. India is also moving to this subquadrant and is reported to be the western reference of the far eastern continental area market.

- To the left of the above mentioned subquadrants is the ML–M corner where one finds Russia and Poland. The position of Russia especially in the 1995–1997 reference frame is worthy of a short observation. It is positioned in that grouping in Table 10.4 because it is "relevant for the market for its educational and historical relevance—not just for production and consumption." It is interesting to note that the specialized press [5] has described Russia as "very attractive because high-tech companies could hire the best Russian experts at low cost in the fields of fiber optics, nuclear physics and satellite technology.
- At the top left side of the map one finds two countries, Cuba and Vietnam. These two countries are expected to have a transition phase with less political and economic

troubles than Eastern Europe. Vietnam is considered by the specialized press [5] to be very interesting because of its skilled, disciplined and cheap labor force.
- Below the main diagonal there is a set of countries (Indonesia, Colombia, Pakistan, Philippines, and Nigeria) that have a medium economic-financial position but a poor political position. Within this group there are two countries, Columbia and Pakistan, which because of drug trade and investment in the nuclear sector may become a serious cause of instability in the North–South relationship.
- At the end of the main diagonal there are three Latin American countries (Ecuador, Peru, and Bolivia) which even without a negative environment in Latin America do not show clear signs of progress.

10.6 Conclusion

The observations made above on the countries‘ positions, show the effectiveness of the AHP in discriminating between different situations. But there also remain a number of countries in the center of the map that may need further separation, perhaps by expanding the second level criteria. Such work is in progress. It requires user interface modification of software implementation, combining the hierarchic composition and its resulting map. The decision maker is given the opportunity to add criteria, modify their weights and note the resulting map. This modification could allow a fine tuning of the model which would facilitate sensitivity analysis. Sensitivity analysis is particularly needed to deal with political change. It is believed that in the current environment, “Turmoil” is more important than “Strategic relevance”. It seems important to explore changes in countries’ positions by shifting emphasis from the present situation (“Turmoil”) to the long term trend (“Strategic Relevance”). Similarly, by scrutinizing the economic-financial side of the model, it appears promising to assign higher priority to indicators of richness and to the competitive position (GDP per Person, Balance Account/GDP) to obtain greater resolution at the center of the map.

The outcome of this study has been well received within the company with interest being shown by managers through their participation. They began with the final map and worked backwards to the structure of the model making suggestions for further improvements. The map provides evidence for the validity of the impact of macroenvironmental changes on international business and it is a valid support for establishing a connection between scanning the macroenvironment and perceptions of strategic issues [8].

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Chapter 11
An Analytic Hierarchy Process Based Approach to the Design and Evaluation of a Marketing Driven Business and Corporate Strategy

11.1 Introduction

The dramatic changes in the business environment, as highlighted in Table 11.1, suggest that the old and proven ways of doing business may not suffice in assuring survival and growth in the 1990s and beyond. Heightened environmental uncertainty and complexity calls for increased attention to creativity in generating strategic directions for the firm, rigor in evaluating the strategic options on multiple and independent objectives, and vision and focus to assure effective utilization of resources. Most managers could greatly benefit from a framework and methodology which would allow them to accomplish these tasks while at the same time assuring that the strategy is driven by the critical *marketing considerations*. The Analytic Hierarchy Process (AHP) provides such a framework and methodology.

11.2 The Building Blocks of Strategy

A marketing driven strategic business plan requires the generation, evaluation and choice of eight interrelated components:

(1) *Mission*

The mission should offer an explicit, visionary, and unique direction for the entire planning process. It offers a first cut at the determination of the business boundaries of the firm. It also serves to mobilize the firm to act and differentiate it from the others.

(2) *Planning horizon*

Planning should accommodate both the short- and long-term needs of the firm. Explicit tradeoffs between the two time horizons should be identified.

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Table 11.1 The changing business environment

• More intensified and sophisticated competition (from domestic and international firms) and changes in the competitive environment due to the formation of strategic alliances.
• Revolutionary technological developments.
• Increased integration of customer and resource markets.
• Highly volatile economic conditions.
• Changing political/regulatory environment.
• Introduction of innovative marketing and distribution practices and organizations.
• Expanding internationalism of business.
• Changing and more sophisticated consumer markets.
• Heightened awareness of ethical/moral considerations.
• A climate of more litigations (product liability) leading to increased cost and risk of doing business and of introducing innovative new products.

(3) *Environmental scenarios*

Planning should explicitly take into account the expected environment. A clear understanding of the environmental forces facing the firm would aid in generating creative strategic options for turning environmental threats into opportunities. Such scenarios could also provide the basis for the development of contingency plans. While the various environmental forces are often conveniently summarized into one of three scenarios, pessimistic, optimistic, and status quo, a detailed environmental analysis focusing on the market, competition, technology, and other environmental forces is essential if one wants to identify the key threats and opportunities facing the firm. This analysis of the environment can include the identification of likely external and internal problems that might prevent achieving the objectives of the strategic business unit (SBU) and the firm, key internal strengths and external opportunities facing the SBUs and the firm, complete competitive analysis encompassing all the critical success factors facing the firm, and the likely trend in the various external and internal forces, their key interdependencies and expected impact.

(4) *Objectives*

It is imperative that management develop operational definitions of their objectives. The objective—whether it is a desired level of growth in profit and sales, a reduction in downside risk, or some other idiosyncratic management objective—should facilitate the accomplishment of the mission and provide the criteria for evaluating any strategic options.

(5) *Criteria*

The focus of any marketing driven strategy should be the target *market segments*. Since it is often difficult to directly evaluate the impact of market segments on the firm's objectives, an intermediate set of criteria is suggested. These criteria focus on: (a) the attractiveness of the market segment (a composite measure of market attractiveness including variables such as size, growth etc.), (b) the firm's strength in the segment (also a composite score which includes measures of the firm's competitive strengths such as technology, distribution, its market share etc.), and (c) synergy—a dimension recognizing the interdependency among activities which, if not included explicitly as part of the strength dimension, should be used as a separate dimension.

(6) *Market/product portfolio*

Identification of the current, potential, and desired market/product portfolio is the focal point of the planning process. The desired market/product portfolio includes current markets/products and new ones developed either internally or externally (via marketing and advertising). The market/product portfolio is the core marketing dimension of the process. It is this focus on the selection of a portfolio of market segments which differentiates a marketing driven from a non-marketing oriented business or corporate strategy. The portfolio of segments and their associated products define the business boundaries of the firm and to the extent that the firm employs a global perspective, it would also incorporate the portfolio of *countries* by mode of operation. This step often involves three inter-related processes: (a) identification of new market segments (for target product by country); (b) evaluation of the current and new segments on the criteria and objectives specified in points (4) and (5); and (c) the generation of and evaluation of a *portfolio* of products/segments which reflects portfolio considerations such as diversification versus focus or, in the international context, the desired levels of integration and coordination of product/segments across countries.

(7) *Strategic options*

Creative options should be generated to meet the needs of the market segments and offer the firm a unique competitive advantage. These options should identify the major leverage points the firm has (e.g. research and development, manufacturing, marketing, finance etc.) and the strategic thrust most likely to meet three interrelated criteria: (a) meeting the segment needs; (b) differentiating the firm from its competitors; and (c) accomplishing the firm's own objectives. The identification of strategic options should also include determining whether the strategy can be accomplished internally or requires a merger, acquisition, or other forms of strategic alliances. Since the generation and evaluation of strategic options is the primary outcome of any strategy process, it is especially important to assure that before making the final selection, the participating managers examine whether better strategies can be developed by increasing, reducing, eliminating, or adding activities (products, segments, countries, distribution systems etc.) or reallocating resources among the various options.

(8) *Functional and resource requirements*

Once the strategic options are identified, the functional requirements (from each operating department) for meeting the needs of the strategic options should be identified and evaluated.

Mission:	Achieve Leadership Position in the XYZ Market				
Planning Horizon:	Short Term		Long Term		
Scenarios:	Optimistic	Status Quo	Pessimistic		
Objectives:	Profit	Growth	Downside Risks		
Criteria: Attractiveness	Market Strengths	Business Synergy			
Market/ Product Portfolio:	M. Segment 1 Product 1	M. Segment 2 Product 2	M. Segment 3 Product 2		
Strategic Options (SO) to Meet the Needs of the Segments:	SO1	SO 2	SO 3	SO 4	SO 5
Functional Requirements:	R&D	Manufacturing	Marketing		

Fig. 11.1 The basic marketing driven planning hierarchy

11.3 An AHP Formulation of a Marketing Driven Business and Corporate Strategy

The selected methodology for implementing this approach is the AHP [2, 3]. Following this approach, the entire process can be summarized in a single hierarchy in which the lowest three levels present the desired business and corporate strategies. The evaluation of the strategies must reflect the relative importance of all the considerations at the higher levels of the hierarchy. Thus, in the hierarchy illustrated in Fig. 11.1, the priorities for allocating resources among the functional requirements are weighted (sum of the weights of each row is always 100) by their contribution to the achievement of the strategic options (new acquisitions, new markets to enter etc.). These options are in turn evaluated with respect to their ability to achieve the desired product/market portfolio of the firm. The selected portfolio is in turn evaluated on its market attractiveness, business strengths, and synergy. These composite criteria are then weighted according to their importance to the achievement of the objectives of the firm, which in turn are weighted on their importance under (a) the expected scenarios and their likelihood of occurrence in the short and long term and (b) management tradeoff between short and long term horizons in accomplishing its overall mission.

An AHP-based approach for the development of a marketing driven business and corporate strategy provides:

1. A marketing-oriented approach to strategic planning—this is done primarily through the focus on the market segments, and the design of effective positioning and associated marketing strategies which meet both the segments' needs and management's own objectives.
2. Planning by top management and the management of the strategic business units rather than by a planning staff.
3. A process which encourages and enhances
   - thoroughness in analyzing the situation,
   - creativity in generating strategic options,
   - rigor in evaluating the options.
4. A group process which allows the integration of diverse management perspectives and data. The approach helps top management reach consensus while at the same time identifying important areas of disagreement which require further examination and study.
5. Short operational planning documents (focusing on the selected hierarchy), rather than lengthy reports.
6. A vehicle for coordinating the efforts of the various functional areas and assuring their cooperation in the implementation of an integrated business and corporate strategy.
7. A procedure which encourages sensitivity analysis and experimentation.
8. A continuous *process* which allows for update and modification as needed.

The hierarchy presented in Fig. 11.1 provides the framework for the planning process and a presentation of overall results. The complete results can often be provided in a short report organized along the eight key levels of the hierarchy. Each of the strategy sections (Levels 6, 7, and 8 of the hierarchy) should include the selected strategies and identify:

- specific programs required to implement the strategy;
- required resources;
- expected results;
- individuals responsible for implementation.

11.4 Applications

The marketing driven planning process described in the previous section and outlined in the hierarchy of Fig. 11.1 has been applied in a number of cases ranging from the selection of a portfolio of segments and products to the design of an overall SBU and corporate strategy. These applications involved a number of major U.S., Japanese and Latin American firms. Given the sensitive nature of some of the applications, the discussion in this section will focus on the lessons learned from them, in particular; key conclusions from the applications, modifications made to the basic framework of Fig. 11.1, areas requiring development.

11.4.1 Key Conclusions from the Applications

Reflecting on the experience gained from six applications of the process described in Fig. 11.1, the following conclusions can be reached:

- Top management teams have no trouble using the AHP
- Having a structure such as the one proposed in Fig. 11.1 helps speed and facilitate the planning process
- The process as outlined in Fig. 11.1 can be used both at the SBU and corporate levels
- The development of a mission statement is often a difficult task. The business definition component of the mission is often revised after completing a first run through the hierarchy.
- Regardless of management's initial evaluation of the tradeoff between short and long term, it is helpful to present them with the results of a sensitivity analysis that encompasses the entire range of options from 90/10 short versus long term to 10/90 short versus long term.
- The construction of scenarios is a task requiring significant staff input, especially if this step is used as a basis for situation analysis involving both internal and external forces. New competitive entries, dramatic technological developments, regulatory changes, and significant shifts in the demographic and lifestyle characteristics of the target markets offer useful starting points for the construction of key environmental scenarios.
- All the applications to date have involved multiple objectives. The most common ones are profit and sales levels and growth and reduction of downside risk. Other objectives tend to reflect idiosyncratic characteristics of management. In all cases the relative importance of specific objectives varies depending on the expected scenario. Typical relationships involved increased importance of profits as the scenario became less favorable.
- Most managers have difficulty directly evaluating market segments and businesses as they relate to their firm's objectives. The use of market attractiveness and business strength as intermediary composite criteria does not simplify the process. There is no agreement, however, across the various firms as to the specific components of each of the two criteria. The GE/McKenzie conceptualization offers a good starting point but is often modified by management. Managers also tend to vary in their evaluation of the relative importance of various components of these criteria as well as the relative importance of market attractiveness and business strength—some prefer to focus on attractive markets, while others prefer markets in which they have specific strengths.
- In most applications, synergy was viewed as a separate and significant criterion. Effective evaluation of positive and negative synergy among the segments and other portfolio operations requires, however, the identification of specific dimensions of synergy (e.g. distribution, manufacturing, procurement, etc.).

- The focus on the market segments to be served and their associated products is initially difficult, especially at the corporate level, but once explored, it greatly simplifies and focuses the remaining task of developing creative strategies to satisfy the needs of and benefits sought by the selected segments.
- The evaluation of the current and expanded portfolio of segments and products (on the selected criteria) is a relatively straightforward task. It is easily summarized in matrix form as segment/products by criteria, or on a market attractiveness business strength chart. It is much harder, however, to use the results of this evaluation as a guideline for the selection of innovative portfolio strategies (e.g. diversification, focus acquisitions etc.). Separate analysis should be undertaken focusing on the generation of portfolio strategies presented as a new level in the hierarchy. These portfolio operations reflect the results of the previous analysis and other considerations and should be evaluated on the objectives of the SBU or the firm.
- It has been helpful in all cases to augment the domestic portfolio of market segments and products with a global perspective focusing on segments by products by country by mode of operation. This is not an easy task, and lack of comparable information across countries has been one of the major obstacles. Such an implementation requires heavy reliance on the subjective judgments of experts.
- In a number of cases, management found it helpful to supplement the basic hierarchy with a direct evaluation of the segments and their associated products (and countries by mode of operation) on the requirements for success versus the firm's expected strengths under each of the expected scenarios.
- The generation of strategic options has greatly benefitted from the use of analogies and other approaches for enhancing creativity [4, Chap. 9].
- The focus on market segments and their associated strategic options helps in integrating the various functions (e.g. R&D, manufacturing, finance, marketing etc.) in a coherent, focused direction.
- All the participants in the various applications found the sensitivity analysis to be of great value and a useful input to the revision of previous decisions.

11.4.2 Specific Modifications

In the course of six applications, a number of modifications of Fig. 11.1 were employed. These included the following:

(*a*) *Incorporating a dynamic analysis of the competitors and their likely responses to the firm's strategy*. The basic model does not allow a dynamic competitive analysis and tends to view, as do most planning processes, the competition as part of the environment. To allow for the consideration of likely competitive reactions, the basic approach was supplemented by a parallel hierarchy for the key competitor(s). This involves role playing the competitor(s)' likely actions and reactions. This dynamic AHP framework is illustrated in Fig. 11.2.

	THE FIRM				KEY COMPETITORS			
MISSION:	ACHIEVE LEADERSHIP OF THE XYZ MARKET WHILE MEETING CURRENT LEVEL OF PROFITABILITY AND GROWTH				ACHIEVE LEADERSHIP OF THE XYZ MARKET WHILE MEETING CURRENT LEVEL OF PROFITABILITY AND GROWTH			
SCENARIO:	S1	S2	S3	S4	S1	S2	S3	S4
OBJECTIVES:	O1	O2	O3		O1	O2	O3	
SEGMENT/ POSITIONING:	SEG/POS A	SEG/POS B	SEG/POS C		S/P A	S/P D	S/P E	S/P F
STRATEGIC	ST1	ST2	ST3		ST1	ST2	ST3	ST4

Fig. 11.2 A dynamic AHP approach to competitive strategy analysis

It provides the framework for a series of iterations between the left- and right-hand-side hierarchies. The process starts by identifying the "best" strategy for the firm (say, segment/positioning A and strategic thrust 1). This strategy is now introduced as part of the scenario facing the key competitor (say, scenario 1) and the competitor's best strategy, reflecting our strategy as part of its environment, is now assessed. This strategy (segment/positioning D and strategy thrust 2) is now considered part of the scenario of our firm, and the previous strategy and other strategic options are examined against it to assure that the selected strategy is the best one. The series of iterations can continue until a "quasi optimal" strategy is found. In a number of applications of this procedure, about five iterations were required to select the best strategy.

(*b*) *Developing supplemental hierarchies*. In a number of cases, it was found that the basic hierarchy presented in Fig. 11.1 had to be supplemented with a more specific hierarchy for the completion of specific tasks. For example, in deciding on an R&D/technology licensing strategy, it was found that the top six levels of the hierarchy in Fig. 11.1 provide the basic structure but that the two new and interrelated hierarchies with additional Levels 7 and 8 should be developed. The product concepts most appropriate to reach each segment are placed in Level 7, and R&D project or technology licensing and acquisition options required to develop the product concept in Level 8. A second hierarchy was then developed in which the various R&D projects and technology, licensing and acquisition options (Level 8) were evaluated on a new set of criteria incorporating likelihood of success, expected cost and completion date, and synergy among the projects (as a new Level 7).

11.4.3 Areas Requiring Further Development

The AHP using the market driven hierarchy outlined in Fig. 11.1 works! It can, however, be further improved by:

- Simplifying the data collection task by reducing the number of required judgments.
- Integrating diverse data collection procedures such as the basic reciprocal matrix using a 9-point scale with 100 points constant sum allocation or ranking for the evaluation of a large number of options.
- Integrating other data sources, especially market response functions and environmental scanning and forecasting, with management subjective judgments.
- Incorporating management uncertainty in various judgments.
- Linking the resulting priorities with optimization programs leading to optimal allocation of resources.

11.5 Conclusions

The AHP offers a unique and valuable method for the generation and evaluation of marketing driven business and corporate strategy. The basic hierarchy presented in Fig. 11.1 which focuses on a portfolio of target segments, assures that the planning process will be market driven.

The process has been successfully implemented in six diverse cases. The experience with these applications reinforces the favorable results obtained in many other applications conducted by Saaty and his colleagues. These results suggest that the process is easily implementable and offers a relatively quick and simple approach to business and corporate planning process.

The applications do support the need for further refinement of the data collection part of the process, its integration with other data sources and analytical procedures.

Another interesting future development is the linkage of AHP to a series of expert systems. Expert systems could facilitate the accumulation and synthesis of knowledge, in the discipline itself and in the participating firms, particularly for such processes as portfolio analysis and strategy. Such development can be modeled for advertising messages [1]. Yet, even without such a development the AHP greatly facilitates a marketing driven planning process and encourages the generation of creative solutions and their rigorous evaluation.

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Chapter 12
New Product Pricing Strategy

12.1 Introduction

This chapter presents the development and application of a model for effective decision making in establishing strategies for the pricing of new products. The model developed evaluates all important criteria that need to be considered for the successful implementation of new products in the market. The formulation of the model was tailored for a specific new software product with unique marketing considerations in a well-defined, segmented market. The process used can easily be extended to include other products, provided that model changes and other appropriate parameters realistically describe the problem being analyzed. Such information needs to be established on a case by case basis by the user, for proper validation of the model.

The model has been applied to a case study involving an actual situation related to the introduction of a large new software product in the market place. The analysis performed considered potential sales and customer benefits covering both pessimistic and optimistic scenarios in an attempt to bound the impacts of this new product, and to support the decision on the best pricing strategy for the introduction of this product in the market. The product being marketed is an advanced high technology software program. Potential buyers will be identified by segmenting the market into groups. For example, market research indicates that the client base consists of electric utilities operating nuclear power plants. Due to the homogeneous nature of the client base, and as a result of extensive government regulations, multiple market mixes are not appropriate.

The product was developed to meet the customer's desire to accurately monitor reactor cores by providing advanced technology. The act of tailoring the product to the buyer's desires is consistent with demand-side marketing. Substitute products are not currently available to potential buyers of this new software. This is essential for changing the technological advantage currently present into a lasting commercial advantage.

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The process of positioning allows the supplier to develop a broad range of uses or applications for the new product. It is essential that every effort be made to identify as many applications as possible, both current and future, for this software product's promotional campaign. As the product was designed to meet the demand for sophisticated reactor core monitoring capabilities, one of the primary sources for obtaining information concerning applications of the product will be the customer. The installation of a prototype at a customer's site has provided the opportunity to collect feedback concerning the customer's need for product modifications, enhancements as well as new applications. In addition, the foundation was laid for increasing customer loyalty to the product. Significant data was collected during the on-site demonstration of the software. This provided valuable marketing, research and development insight concerning potential applications in response to future customer needs.

The promotion of a new product encompasses advertising, personal selling, sales promotion and public relations. Brochures, pamphlets, catalogs and other print media, announcing the product, are produced by the in-house marketing department. The documents are periodically updated to reflect the new applications and enhancements that are identified as a result of marketing research and customer feedback. Supplies are given to the nuclear fuel vendor to be distributed during on-site visits to the plants. In addition, plans have been made to produce a video storyboard to be used in conjunction with more formal product presentations to senior management and regulatory agencies. Although the product will be sold by the nuclear fuel vendor, the marketing department provides follow-up assistance to potential buyers, attends trade shows and provides literature, and operated a speakers bureau service. The strategic marketing plan targets a very narrowly defined market segment. Marketing is essential due to the constant rate of change in a high-technology market and to ensure that potential buyers are fully informed of the software's capabilities. Following several years of development, the program is now available for customers.

Another dimension which is important in the development of a marketing strategy is product pricing. Classical economists in the eighteenth and nineteenth century viewed price as responding solely to market conditions. They believed that prices were a function of supply and demand alone. The economic system was supposed to automatically set the price of all products.

Just over 40 years ago, an economist, Gardiner C. Means, defined the term "administered prices" to describe goods which had rigid prices and did not fluctuate with a variation in demand. Today, "administered prices" are formulated in corporate offices of most companies as a matter of operating policy, financial planning, and marketing strategy. Nowhere is an "administered price" more a factor than with a new product. For a new product, there is a range of alternative pricing policies which can be adopted. Each alternative policy suits specific circumstances. The pricing policy alternatives relevant to our product are skimming, penetration, and strategic.

Skimming achieves the maximum profit in the shortest possible time by charging the highest price the market will bear. *Penetration* achieves the maximum market penetration by charging a low price to create a large sales volume. Penetration policies typically require that the company be convinced of the long-run demand elasticity of the product. Long-term cost recovery must be acceptable, and long-term profits desirable. Yet another alternative is *strategic pricing*. Strategic pricing is an extreme form of penetration pricing. No profit is generated; only fixed and variable costs are recovered. A few situations suggest strategic pricing. Strategic pricing involves more than just the product being sold. It requires a long-term perspective on the part of the entire company.

Pricing is the major decision facing management during the birth of a new product because it determines the ultimate contribution to short, medium, and long-term profitability of both the product and the company.

12.2 The Analytic Hierarchy Model

All the parameters included in the model developed have been tailored for the specific case of a new computer program software that provides sophisticated capabilities for the monitoring of nuclear reactor cores. As such, this product has targeted specific customers, which required unique considerations of the market and distribution channels. However, the considerations made in the model and the hierarchy can easily be extended for different situations, if appropriate criteria are identified and specific judgments are used in the analysis.

Several different scenarios were evaluated to consider the uncertainties in the planning scheme over the next 5 years; the time period of acceptance for this new product in the market.

The product considered is a sophisticated computer program for the support of operation in Nuclear Power Plants, with the capability to display margin to safety limits. However, it is not part of the plant automatic protection systems. This system provides information for operators, site engineers and designers on reactor core performance. The software operates on engineering workstations and integrates several independent functions at the power plant site.

This software has been under development for 4 years, and has resulted in a large computer program of approximately 70,000 lines of code. Considering the technical complexity and the interactive nature of its user interface, an extensive site demonstration was conducted during the past year, with the installation of the product at a host site for use in actual situations. This demonstration program was very successful, leading the Beta-Test customer to acquire the software for all its plants. It provided significant and valuable data on product modifications and enhancements that address future customer needs. This product introduces leading technologies in both software and hardware, with the potential of altering processes that can limit its acceptance.

The market for this software consists primarily of Electric Utilities that operate nuclear Power Plants. In addition, the product is more applicable to a specific class of reactors. This clearly identifies the potential participants in the market, thereby bounding clearly the potential demand for the product. The finite number of consumers involved and the highly technical nature of its application determine that an extremely focused marketing strategy should be employed.

At present there are no competitors who can offer products of similar technology and capabilities. However, there are strong indications that software is being developed that may match this product's functions, but such developments are at least 2–3 years from any practical implementation.

Since there is product exclusivity in the market, the model and economical considerations made in this paper are representative of a monopoly. However, initial market analysis has indicated that price is still an important parameter due to the approval of customers Operating and maintenance expenses by Public Utilities Commissions.

No specific considerations are required on distribution channels for the product as marketing, delivery and support will be provided by the nuclear fuel vendor. Commercial and technical relationships with potential customers are well established. These relationships provide an additional competitive advantage as competitors cannot offer the same level of support nor do they have the same leverage in packaging their product with other large contracts.

This software also provides other benefits to the supplier. In addition to sales, it strengthens existing supplier-customer relationships. The implementation of this product will act as a small barrier for competitors since they will be required to invest substantially supporting the system. It has a significant impact on the technical processes involved as it introduces new approaches that alter the technical interface between supplier–customer. These changes provide opportunities for additional businesses and differentiation in the market place, which are more significant than the technological leadership introduced by the product.

In sum, the objective of this model is:

> To determine the best pricing strategy for a new software product that takes into account relevant considerations of market share and return on investment, and accounts for the overall uncertainties associated with product acceptance projections.

The hierarchy designed for this model (see Fig. 12.1) evaluates the pricing strategies according to defined limits of relevant business criteria. Each needs to be considered for the particular problem in question, as well as for different scenarios that reflect uncertainties in the planning period.

12.2.1 Time Horizon Scenarios

The Pricing Model described here has been established to guide pricing decisions of a new software product. It includes alternatives on time horizon uncertainties about the market behavior over the next 5 years. Three scenarios have been included in the hierarchy:

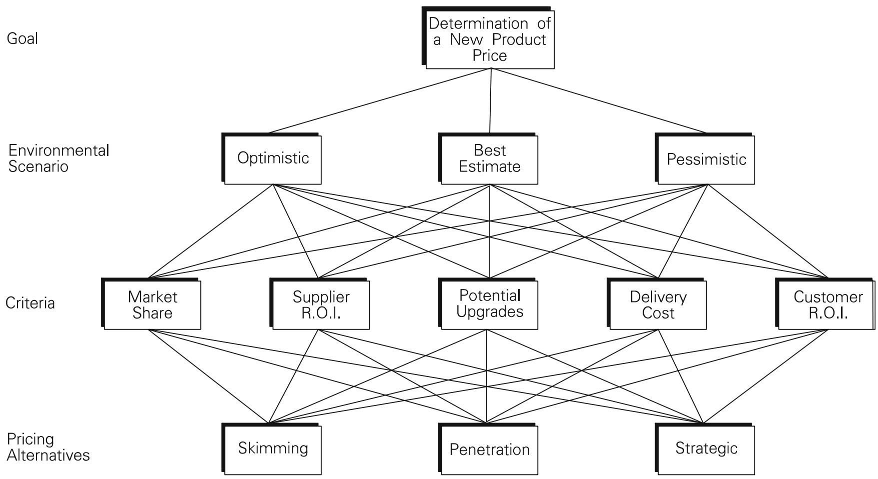

Fig. 12.1 New product pricing hierarchy

- The Optimist Market Scenario is the result of a set of circumstances that lead to the capture of the entire market, i.e., maximum market share,
- The Pessimistic Scenario establishes a set of potential situations that lead to a minimum market share, and
- The Best Estimate Scenario is the middle of the road, in which a realistic market potential will be possible for this product. Preliminary market research has indicated that this approach is the most realistic in the near term until the technology is fully approved by the licensing authorities.

These scenarios are described in detail in Table 12.1.

The potential pricing alternatives need to be evaluated according to the set of criteria relevant to the business parameters established for this product.

12.2.2 Criteria

Five criteria that influence the product price were identified. In the Analytic Hierarchy Process, each is compared against the others to determine their degree of influence on the goal:

Market—The potential market share achievable is an important parameter in defining the product price, as product development costs make a large contribution to the total product costs, and therefore, the profit. In addition, market share is important from the perspective of potential additional business through product upgrades and preempting the possibility of competitor entry into the market.

Supplier ROI—The Return on Investment is another important business consideration from the suppliers point of view, and product sales should meet

Table 12.1 Environmental scenarios

Skimming	*Penetration*	*Strategic*
The product has a short life-cycle or has a high rate of innovation incidence, such as fashion	For some products it is best to discourage competitive entry into the market, particularly if a high level of investment is required	The company takes a very long-term view and wishes to preclude all competitors from the market. Profit can eventually be taken from enhancements later sold which will expand the capabilities of the product
The product sells in quality markets where sales seem relatively inelastic to price but responsive to promotion	The product may have a high degree of elasticity in demand resulting in increased revenue via price reduction	The company sells related hardware or services and uses the software to secure the customer into its system. An example of this is the airline ticketing system, SABRE, developed and marketed by American Airlines
The product is of a new concept for which the buyer has not means of comparison for value and utility	Some section of the market may not currently be tapped by existing high-priced products	
The product can incorporate improvements and modifications to meet changing consumer concepts of utility without price changes	Economies of scale may dictate a high sales volume	
The product is such that future price reductions will enable it to reach different consumers of a more elastic nature, thus widening the product's market		
The company may have limited manufacturing facilities or sales force. In such circumstances, a small, but highly profitable segment of the market may be best		

minimum returns specified by Corporate guidelines. The ability to continue to develop new products depends on the success in the market, and to a great extent product acceptance is dependent upon price.

Product Upgrades—As described earlier, the initial installation of the product enables the deployment of a strategy of upgrades and enhancement that extend the product maturity cycle.

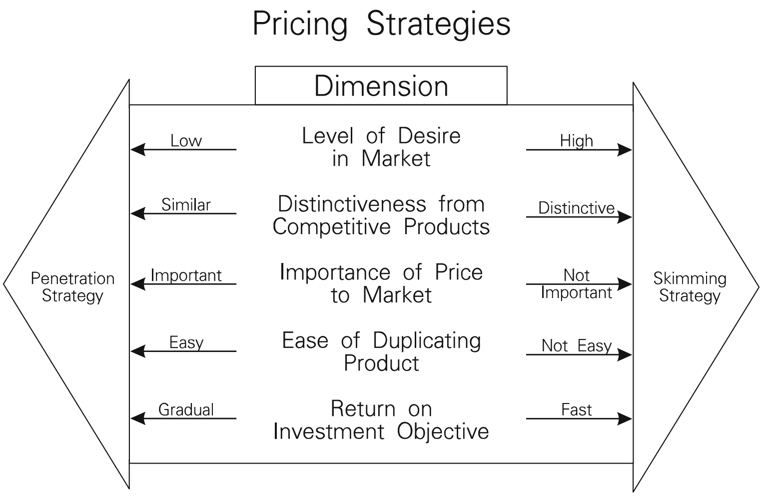

Fig. 12.2 Pricing strategies

Delivery Cost—Product delivery is another component in the total product cost. Fixed costs will be large in proportion to market share, and variable costs basically steady and small in comparison to total costs.

Customer ROI—The success of the product in the marketplace is driven by the value that this product brings to customers. This software provides several areas of benefits, as discussed earlier, and the ultimate ROI from the Customer viewpoint is not particularly sensitive to price. However, due to limitations in operating budgets initial price is an important consideration in the decision to acquire the software.

12.2.3 Alternative Strategies

The pricing strategies developed for this model address the classical approach of marketing high technology products, and the seller's objectives (Fig. 12.2):

Skimming Strategy—This strategy suggests to demand a premium for the product, which will result in a limited number of sales but with high overall ROI for the seller. This strategy could be justified in that the product provides significant benefits for customers, and the technology lead over competitors. However, it is the alternative with maximum risk, in that a high price makes the justification of the product purchase more difficult. There are several examples in product implementation that have adopted this approach with disastrous results.

Penetration Strategy—The Penetration Strategy proposes a pricing level that provides certain incentives for more customers to purchase the software, and at the same time, provide a good return to the supplier. This is a middle of the road approach that attempts to balance benefits for both the supplier and customer while ensuring a broad market for the seller.

Strategic Strategy—In the Strategic pricing strategy, the main consideration is to eliminate any barrier towards product acceptance, and price the product as near to cost as possible. Minimum price will capture the maximum market share possible, but will minimize supplier ROI. However, the market share position will permit the development of additional business through sale of product upgrades, and provide for the maximization of the total product related revenues in the long run.

12.3 Model Application

In this section, we discuss the results obtained with the model developed in Sect. 12.2. In addition to the reference model result, a sensitivity study was conducted to establish the reasonableness of the reference case and to identify the conditional parameters that would lead to a different course of action. The results of the sensitivity analysis provide insight into trigger points that could be established and monitored during the implementation of this product, and would indicate the need for reassessment of the initial pricing position.

12.3.1 Reference Case

The model was input into the "Expert Choice" AHP-based software program and run to define the base case pricing strategy for the new product introduction. As discussed in the previous section, fixed and variable cost structures and the required supplier return on investment were provided by corporate instruction. Pairwise comparison values of the elements within the model were designed by consensus within the group.

Based on the parameters discussed and the synthesis of the relevant criteria we conclude:

Alternatives	*Priorities*
Skimming	10.8%
Penetration	42.8%
Strategic	46.4%

and hence, the overall best pricing strategy for the new product is the *Strategic* alternative.

The strategic pricing approach incorporates the lowest price of the three strategies and facilitates product acceptance. In this case study, significant importance was placed on market share and provision for future profits through upgrades to the software; a long-term approach to economic performance of the product is used. Supplier's return on investment and delivery costs were the secondary concerns and customer return on investment was the least significant concern.

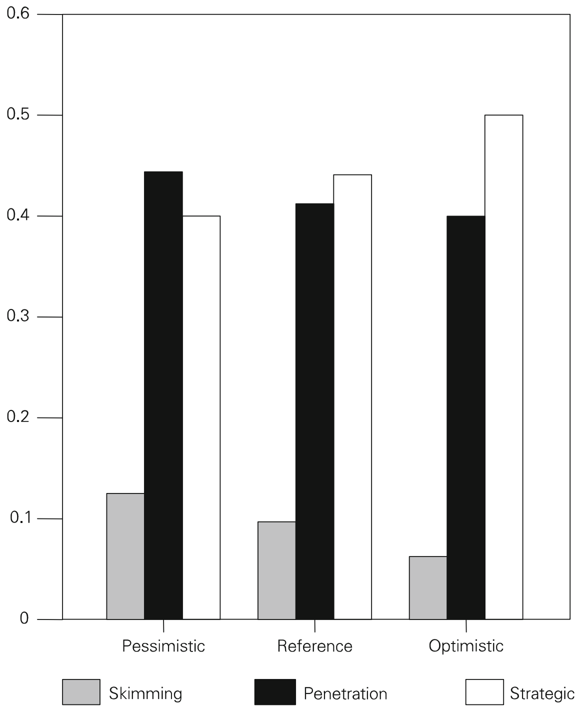

Fig. 12.3 Strategy sensitivity on market—base case

12.4 Sensitivity Analysis

Sensitivity tests of the model to variations in the market demand were run to aid in the prediction of future changes in pricing strategy. In addition, the model's sensitivity to alternations in corporate strategy with respect to return on investment was tested.

Figure 12.3 illustrates the effect of the variations in the market strength on the pricing strategy employed in the reference case. For example, in a pessimistic market environment, *strategic* pricing is the most desirable approach. In a weak market environment, the supplier must be concerned with recouping sunk costs to a large extent and realize that a weak performance will bear on the viability of future projects.

As the estimate of market strength increases, a continued low price will provide maximization of market share and thus eliminate barriers to product acceptance. The *strategic* approach is the best alternative for this reason as well as the firm's continued emphasis on its long-term objective of additional business due to upgrades.

In an optimistic market environment, the *penetration* approach to pricing becomes increasingly more desirable than the *strategic* approach. More emphasis will be placed on the suppliers return on investment.

Market Uncertainties—Variations in the demand for the new product results in a shift in the pricing strategy. As presented in Fig. 12.4, an expanded (optimistic) market would strongly reinforce a continuation of strategic pricing. A shift in market demand to one worse than predicted also dictates a shift in pricing policy.

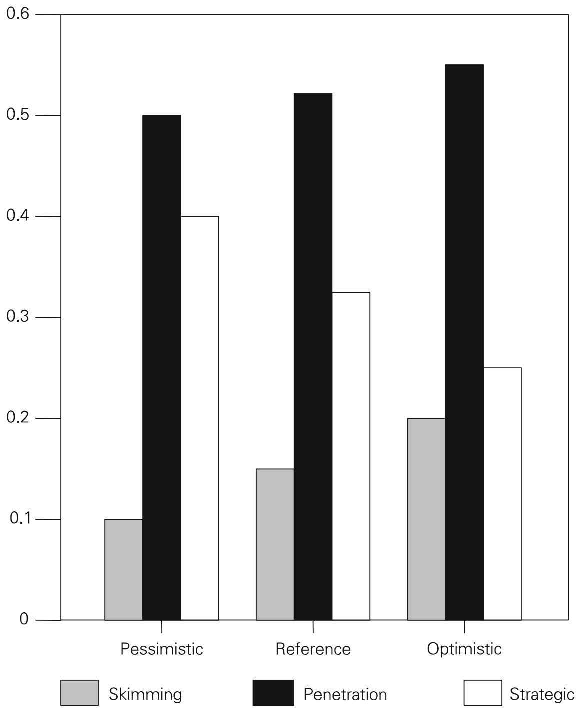

Fig. 12.4 Strategy sensitivity on market—aggressive

The model is sensitive to reduced demand and indicates that a "soft" market would signal a switch to penetration pricing.

Corporate Objectives—Additional sensitivity tests were also run on this model to evaluate the effect of variations of corporate strategy on the pricing strategy. A shift in emphasis from long-run planning to short-run returns was tested. With the emphasis on short-run profits, the optimal strategy in all environmental scenarios, as defined by the model, is penetration strategy (Fig. 12.4). A comparison of short-run vs. long-run pricing strategies in a best estimate environment is presented in Fig. 12.5.

12.5 Conclusions

The decision as to how to price any product is a complex one. This process must be approached with a systematic methodology that accounts for all important criteria. The criteria used will vary with the product. In this study, the product being priced is an advanced software program that is used to monitor nuclear reactor cores. The market mix is limited due to the nature of the possible customers. This market can be thought of as a monopoly in that there is only one viable producer of this product.

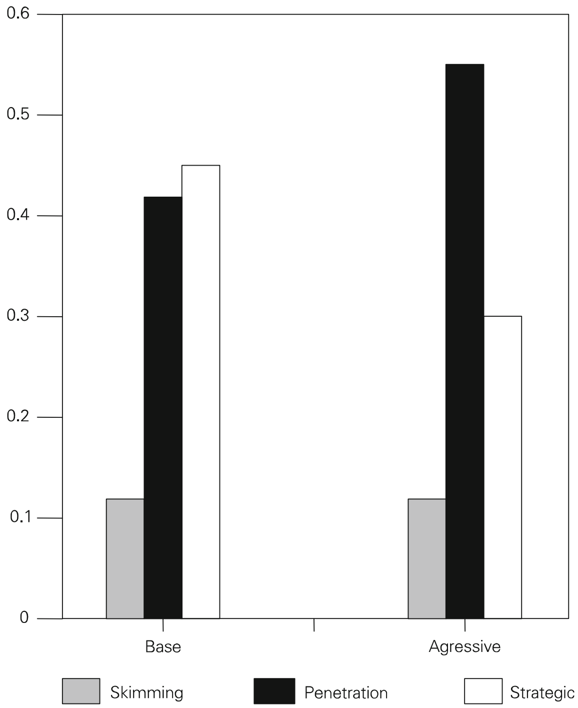

Fig. 12.5 Strategy sensitivity to changes in corporate objectives

A review of the market showed that there are three possible pricing strategies for this product. These include:

- Skimming—Maximum profit in the shortest amount of time.
- Penetration—Low price, high market share.
- Strategic—Extreme variation of penetration. Lowest price for the greatest market share.

It was from these three strategies that a best case must be selected. The results demonstrated that in the long-run, the *strategic pricing* approach would be best for this product. However, sensitivity analysis of the model showed that a switch to *penetration pricing* may be necessary if the market were to turn soft. In addition, if the emphasis of the company was to shift to short run profits, *penetration pricing* would become the strategy of choice regardless of the market strength.

A final conclusion is that the results of the sensitivity analysis could be further studied to precisely determine trigger points where a change in pricing strategy would be necessary. These trigger points would be the result of any change in company direction that altered the assessment of the model criteria or a significant change in the market conditions.

Chapter 13
Incorporating Expert Judgment in Economic Forecasts: The Case of the U.S. Economy in 1992

13.1 Introduction

Professional and academic economists employ a variety of techniques and commit significant amounts of time and financial resources for the purpose of producing macroeconomic forecasts. This chapter illustrates the use of the Analytic Hierarchy Process in forecasting. It integrates macroeconomic theory, historical evidence (as reflected, for example, in formal forecasting models) and expert judgment. Importantly, in the context of current efforts to forecast the future course of the U.S. economy, expert judgment facilitates the incorporation of structural changes into such forecasts.

13.2 On the Role of Judgment in Economic Forecasting

Conventional approaches to macroeconomic forecasting tend to be constrained by the estimated values of the parameters and intercept terms imbedded in the multi-equation forecasting models which typically are employed to produce "first-cut" forecasts of relevant endogenous variables. Additionally, the values of a large number of "exogenous" variables (relating to the future course of monetary and fiscal policy, the value of exports, etc.) must be subjectively estimated on the basis of available evidence and consensus judgment. The initial forecasts produced by the raw models are then typically adjusted by the use of "add" or "fudge" factors, most commonly in the form of shifts in the values of previously estimated intercept terms. This procedure is employed in order to produce forecasts which are consistent with recent values of key endogenous variables when it is evident that a shift of some kind has occurred in portions of the underlying structure of the model [1], pp. 108–110; [3], p. 256). Such exercises also provide ample opportunity for re-setting the values of exogenous variables.

T. L. Saaty and L. G. Vargas, *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*, International Series in Operations Research & Management Science 175,
DOI: 10.1007/978-1-4614-3597-6_13,

Studies of “ex ante” forecasts produced by the builders of major models using add factors suggest that these forecasts have been more accurate than the “ex post” forecasts produced by the models themselves, even when the same add factors were employed. Fair ([3], p. 263) wrote:

> In other words, the use of actual rather than guessed values of the exogenous variables decreased the accuracy of the forecasts… This conclusion is consistent with the view that the add factors are (in a loose sense) more important than the model in determining the ex ante forecasts…

All of this suggests that macroeconomic model builders/forecasters are well aware of the limitations of their underlying models and the need to incorporate subjective judgments, especially in the face of structural shifts in the models. However, these judgmental adjustments are necessarily non-systematic and ad hoc in nature.

Rather than further critiquing this approach, however, we instead provide an alternate which is both systematic and consistent in its ability to capture the impact of structural changes. While we have not illustrated this alternative by adapting a formal macroeconomic forecasting model, we do employ an eclectic conceptual framework grounded in modern macroeconomics. Our alternative, moreover, could also be readily employed to enrich forecasting exercises based on formal models (e.g. generating add factors more systematically and consistently; adjusting the values of exogenous variables). In this respect, the two forecasting approaches can be seen to converge quite compatibly.

13.3 The Setting: A Sluggish Recovery/Structural Change

The National Bureau of Economic Research (NBER), utilizing a panel of academic experts, has by consensus been given the responsibility for dating the actual turning points in the U.S. economic cycle. In addition to changes in real GNP or GDP[1] (New York Times, June 18, 1992), that organization arrives at its assessments by utilizing a variety of economic indicators. In December of 1992, the NBER announced (New York Times, December 23, 1992) that the trough of the current cycle occurred in the first quarter of 1991.

The severity of a recession as well as the strength of a recovery should be measured by both the cycle’s amplitude and duration. With regard to its most recent cyclical phase, for example, the U.S. economy apparently peaked in the second quarter of 1990, and then proceeded to fall in terms of real GNP for the next three quarters at an annual rate of 2.6%. However, the economy had technically been expanding since second quarter of 1991, and was growing at an annual rate of about 1.69% from the first quarter of 1991 through the third quarter of 1992. The Annual

[1] An alternative measure of U.S. aggregate economic activity is now used by the U.S. Department of Commerce: namely, gross domestic product (GDP), which nets out international factor payments and receipts. We will continue to cite GNP patterns in this chapter for historical purposes. Currently, real GNP is running slightly higher than real GDP.

Table 13.1 Recent economic expansions

Real GNP growth (average annual rates)				
Trough	November 1970	March 1975	November 1982	1st quarter 1991
1st six quarters	5.9%	6.3%	6.8%	1.7%

rate of the expansion through the second quarter of 1993 is now stronger but still quite modest, about 2.7%. Thus, even if we agree with the NBER's dating of the most recent cyclical trough, the expansion's initial phase must be judged the weakest in recent history. Table 13.1 provides evidence for the first six quarters of the three previous expansions side by side with the most current expansion (using the NBER dates for the troughs):

Survey of Current Business, US Department of Commerce, various issues, NBER dates are used to identify troughs

Moreover, other general economic indicators have performed sluggishly. Most importantly, total employment failed to grow appreciably during this putative expansion, unlike the three previous expansions.

It needs to be emphasized that much of this information was unavailable to us when the authors convened in late-December 1991/early January 1992 to engage in an exercise aimed at forecasting the trough of the current cycle. At that point, we did not subscribe to the notion that a less than 1.0% rate of real GNP growth from the first quarter 1991 to the third quarter 1991 (the latest data then available) signified an economic expansion, especially when coupled with other economic data being reported at that time. When we reconvened in May 1992 to review our previous assessment and to engage in an exercise aimed at forecasting the strength of the eventual recovery, the annual rate of real GNP growth through the fourth quarter of 1991 (the latest then available) had apparently actually weakened marginally. The rate of real GNP growth between the last quarter of 1991 and the first quarter of 1992 subsequently rose to 3.5% on an annual basis, only to decelerate again in the second quarter to something of the order of 0.7%. The growth rate then grew substantially in the third quarter of 1992, perhaps signalling the onset of a stronger recovery. Again, this information was obviously not available to us in early May of 1992, though other negative economic portents certainly were.

It is also instructive to compare the forecasts produced in this chapter with those prepared at the time by professional economic forecasters. *Blue Chip Economic Indicators* is a monthly publication which reports the consensus forecast of 50 major economic forecasters, including teams at universities, banks, corporations, forecast specialist firms, and professional and credit evaluation institutions.

In December of 1991, the Blue Chip CONSENSUS forecast for real GNP growth in 1992 was 2.2%. This represented a reduction of two-tenths of a percentage point from that projected in the previous month. However, the CONSENSUS reported that: "…, the seeds of growth have been planted and next spring should see a sustained economic recovery begin to sprout." Further, the CONSENSUS in March of 1992 indicated that the economy is "…perking up…" and suggests "…guarded optimism." for the expected recovery. More importantly, the CONSENSUS shifted to a “green” banner in April 1992, indicating that the economy was turning around and expanding above the long-range growth potential of 3%.

The foregoing provides the context for the forecasting exercises of December 1991 and May 1992 which are described in this paper. As noted, the NBER has now rendered its judgment concerning the date from which the economic recovery began. Ensuing events will also disclose the eventual strength of that recovery. However, as will be illustrated in a later section of this paper, our judgment in December 1991 was that a meaningful turning point in the current cycle was still a number of quarters in the future. Our judgment in May 1992, moreover, was that the strength of the eventual recovery was likely to be quite weak when compared to previous expansions, owing chiefly to the “braking” influence of major structural changes then taking place in the domestic and global economies (specifically, such factors as the de-emphasis of production based on national defense and the increasing integration of world financial markets).

13.4 Application of AHP to the Macroeconomic Forecasting Problem

Our forecasting exercises employed the AHP to address two critical issues germane to forecasting: the timing and the strength of the expected recovery. The timing issue required us to incorporate into the forecasting exercise the sequence of global events of the previous two and a half years. In our view these events had been forging a restructuring of global resources and institutional arrangements. With regard to the strength of the recovery, our task was to think through the ways in which such restructuring acts as a moderating influence on the performance of the key macroeconomic variables most proximately connected to the U.S. economic cycle. Our first exercise thus sought to forecast the most likely period for the turnaround, while the second tried to predict the strength of the ensuing recovery.

13.4.1 Decomposition of the Problem Hierarchically

As noted, the objective of the first exercise was to forecast the most likely date of a turnaround. The top level of both exercises consists of the factors representing the forces or major influences driving the economy. These forces are grouped into two categories: “conventional adjustment” and “economic restructuring.” Both of these categories are decomposed into subfactors represented in the second level. For the timing forecast, the third level consists of time periods in which the recovery can occur. Figure 13.1 provides a schematic layout used to forecast the timing of the economic turnaround.

Because conventional adjustment and restructuring are both time dependent factors, their relative importance had to be established in terms of each of the four

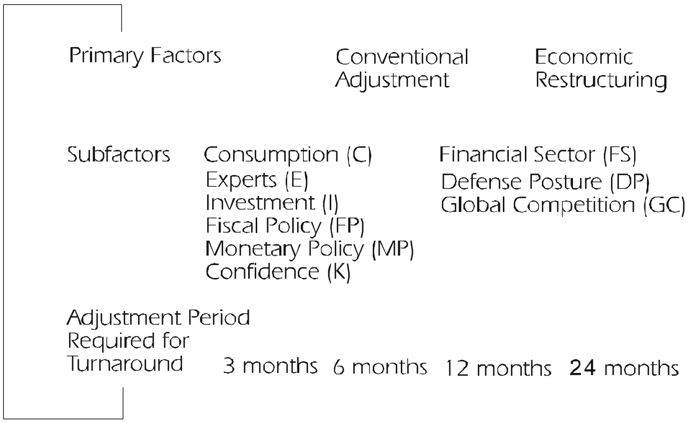

Fig. 13.1 The U.S. holarchy of factors to forecast a turnaround in economic stagnation

contrasting time periods used to compose the forecast time frame. Thus, instead of establishing a single goal as one does for a conventional hierarchy, we used the bottom level time periods to compare the two factors at the top. This entailed the creation of a feedback hierarchy known as a "holarchy" in which the priorities of the elements at the top level are determined in terms of the elements at the bottom level, thus creating an interactive loop.

With regard to forecasting the strength of the recovery, we used a standard format for the hierarchy, beginning with the primary factors of conventional adjustment and economic restructuring. Their importance for this part of the exercise was established over a six month period after the turn around. Figure 13.2 is a standard hierarchy, and provides a representation of relevant factors.

Conventional adjustment assumes a status quo with regard to the system of causes and consequences in the economy. The presumption is that the underlying structure of the economy is stationary. Forecasting is possible within acceptable ranges of error. This is achieved by tracing the existing network of stimulus/response patterns initiated by a perturbation in a fundamental parameter of the economy. In our view, conventional adjustment can formally be divided into six macroeconomic subfactors that occupy the second level: consumer spending, investment spending, exports, indicators of confidence in the economy, fiscal policy, and monetary policy. We recognize that these subfactors are in some instances interdependent.

Viewed independently, for example, a lowering of interest rates by the Federal Reserve should induce portfolio rebalancing throughout the economy. In turn, this should reduce the cost of capital to firms and stimulate investment. Simultaneously, it should reduce financial costs to households and increase their disposable incomes. Any resulting increase in disposable income stimulates consumption and at the margin has a positive impact on employment and GNP. However, all of this assumes that the linkages of the economy are in place and are well understood.

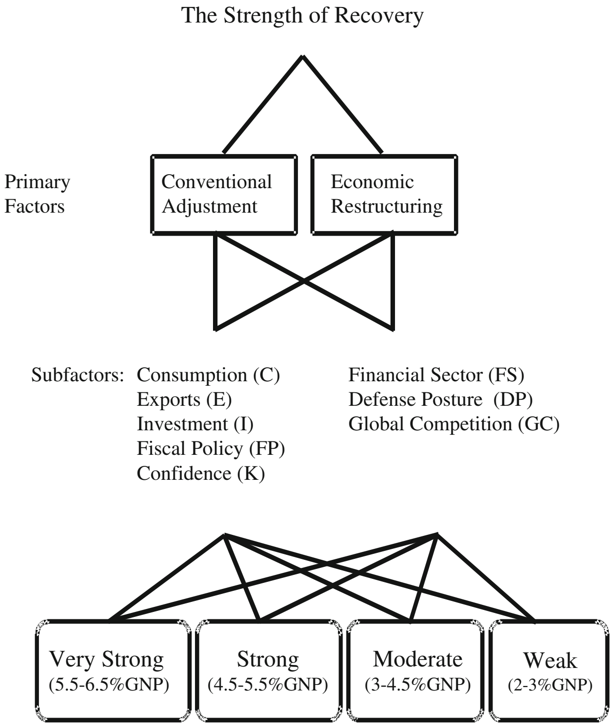

Fig. 13.2 Strength of recovery hierarchy

Recent events in the global economy will exert fundamental changes in the way the U.S. economy will operate for the next several years and beyond by inducing an economic restructuring. The Gulf War, the demise of centrally planned economies in eastern Europe and the former Soviet Union, the integration of western Europe, the emergence of newly industrialized economies, and the quickening integration of financial sectors throughout the world are all events which suggest an economic structure that is not stationary but is undergoing dramatic change. Prudent recognition of these facts suggests that patience and monitoring of events are appropriate guidelines for public policy.

With regard to the nature of the current economic restructuring, we specifically recognized in this exercise the transformation of the financial sector, the reduction in the defense-based component of the economy, and the changing global competitiveness position of the U.S. economy as additional subfactors in the second level.

Changes in the domestic economic environment induced by these factors affect the economy in ways that are not well understood and are too complex to pursue here. We summarize these effects by estimating the impact of each subfactor on the expected length of time prior to a turnaround, as well as their impact on the relative strength of the ensuing expansion.

With respect to the timing of the turnaround, we considered four possible time periods of adjustment in the third level as a reasonable breakdown of time in periods long enough to discern change in making the comparisons, but short enough to consider all possible changes over the two year horizon of the forecast. These periods were: 3 months, 6 months, 1 year, and 2 or more years, dated from late December 1991.

With regard to the strength of the expansion, our May 1992 exercise employed ranges of average real GNP growth. Specifically, we considered the following possible outcomes: very strong (5.5–6.5%), strong (4.5–5.5%), moderate (3.0–4.5%), and weak (2.0–3.0%). These ranges represent annualized measures of percentage change in real gross national product for the first two years of the recovery. While the ranges are somewhat arbitrary, they generally reflect actual experiences during various post World War II cyclical expansions.

13.4.2 Pairwise Comparison

After decomposing the two problems hierarchically (i.e. the time period of the expected turnaround and the relative strength of the ensuing recovery), the second step in the process was to compare the factors as to their relative importance in affecting each of these questions in terms of their parent factor in the adjacent level above. Accordingly, comparisons were carried out using the AHP's nine point scale.

An illustration of the use of this scale to represent judgments proceeded in the following manner: if conventional adjustment factors were considered to be "strongly more important" than economic restructuring factors for an economic turnaround to occur within six months, the number five (5 times) would have been assigned to the pairwise comparison of conventional adjustment with economic restructuring.

The judgments with regard to the identification of factors as well as the comparisons of relative impact and strength of factors were conducted by the authors, who assumed the role of representative "experts". Obviously, the outcomes are heavily dependent on the quality of those judgments. As noted, the first exercise (timing of the turnaround) was conducted during the third week of December, 1991 and refined during first week of January, 1992. The estimation of the strength of the recovery was conducted during the second week of May, 1992.

Tables 13.2, 13.3, 13.4, 13.5, 13.6 and 13.7 provide the associated matrices of relative comparisons as well as a limiting and completed "supermatrix."

For example, in Table 13.2, when comparing consumption with investment as a means of conventional adjustment, consumption is thought to be strongly more important and a 5 is entered in the first row and third column (1, 3). Its reciprocal value of 1/5 is entered in the (3, 1) position. On the other hand, when compared with confidence, consumption is not more important but confidence is strongly more important and a 1/5 is entered in the (1, 4) position and a 5 in the (4, 1) position. All other judgments follow this procedure. The vector of weights is derived from the matrix as the principal eigenvector of the matrix as described in Sect. 13.3.

Table 13.2 Matrices for subfactor importance relative to primary factors influencing the timing of recovery

Panel A: Which subfactor has the greater potential to influence conventional adjustment and how strongly?

	C	E	I	K	F	M	Vector weights
Consumption (C)	1	7	5	1/5	1/2	1/5	0.118
Exports (E)	1/7	1	1/5	1/5	1/5	1/7	0.029
Investment (I)	1/5	5	1	1/5	1/3	1/5	0.058
Confidence (K)	5	5	5	1	5	1	0.334
Fiscal policy (F)	2	5	3	1/5	1	1/5	0.118
Monetary policy (M)	5	7	5	1	5	1	0.343

Panel B: Which subfactor has the greater potential to influence economic restructuring and how strongly?

	FS	DP	GC	Vector weights
Financial sector (FS)	1	3	3	0.584
Defense posture (DS)	1/3	1	3	0.281
Global competition (GC)	1/3	1/3	1	0.135

Note to Tables 13.6 and 13.7: Now we group all the derived vector weights as columns in the appropriate positions of a matrix of mutual influences known as the supermatrix. For example, the first vector we derived from the matrix of subfactors of conventional adjustment is placed in the first column next to the six subfactors and under conventional adjustment. The factors are listed systematically so that the right vectors are listed to indicate the impact of the relevant factors on the left on the factors at the top. The supermatrix, being stochastic (with columns adding to one) is then raised to limiting powers to capture all the interactions and obtain the steady state outcome in which all columns within each block of factors are the same. We are particularly interested in the two identical columns at the bottom left corner of the matrix of Table 13.7. Either one is given by (0.224, 0.141, 0.201, 0.424).

To obtain the forecast we multiply each value by the midpoint of its corresponding time interval and add (as one does when evaluating expected values). We have

$$0.224 \times 1.5 + 0.151 \times 4.5 + 0.201 \times 9 + 0.424 \times 18 = 10.45\text{months}$$

from early Jan. 1, 1992. Note that at times the resulting supermatrix may not be stochastic which would then require weighting each cluster of factors as it impacts another cluster at the top.

Table 13.3 Matrices for relative influence of subfactors on periods of adjustment (months) (conventional adjustment)

	3	6	12	24	Weights
Panel A: Relative importance of targeted time periods for *consumption* to drive a turnaround					
3 months	1	1/5	1/7	1/7	0.043
6 months	5	1	1/5	1/5	0.113
12 months	7	5	1	1/3	0.310
24 months	7	5	3	1	0.534
Panel B: Relative importance of targeted time periods for *exports* to drive a turnaround					
3 months	1	1	1/5	1/5	0.083
6 months	1	1	1/5	1/5	0.083
12 months	5	5	1	1	0.417
24 months	5	5	1	1	0.417
Panel C: Relative importance of targeted time *investment* to drive a turnaround					
3 months	1	1	1/5	1/5	0.078
6 months	1	1	1/5	1/5	0.078
12 months	5	5	1	1/3	0.305
24 months	5	5	3	1	0.538
Panel D: Relative importance of targeted time for periods periods for *fiscal policy* to drive a turnaround					
3 months	1	1	1/3	1/5	0.099
6 months	1	1	1/5	1/5	0.087
12 months	3	5	1	1	0.382
24 months	5	5	1	1	0.432
Panel E: Relative importance of targeted time periods for *monetary policy* to drive a *activity* to turnaround					
3 months	1	5	7	7	0.605
6 months	1/5	1	5	7	0.262
12 months	1/7	1/5	1	1/5	0.042
24 months	1/7	1/7	5	1	0.091
Panel F: Expected time for a change of confidence *indicators of consumer and investor* support a turnaround in the economy					
3 months	1	3	5	5	0.517
6 months	1/3	1	5	5	0.305
12 months	1/5	1/5	1	5	0.124
24 months	1/5	1/5	1/5	1	0.054

For each panel, which time period is more likely to indicate a turnaround if the relevant factor is the sole driving force?

13.4.3 Synthesis/Results

When the judgments were made, the software package known as "Expert Choice [4]," in which the AHP procedure is embedded, was used to perform a synthesis which produced the following results:

1. A meaningful turnaround in the economy would likely require an additional ten to eleven months, occurring during the fourth quarter of 1992. This forecast was derived from weights generated in the first column of the limiting matrix in

Table 13.4 Matrices for relative influence of subfactors on periods of adjustment (months) (Economic Restructuring)

	3	6	12	24	Vector weights
Panel A: Most likely length of time for restructuring of financial system to support a turnaround					
3 months	1	1/3	1/5	1/7	0.049
6 months	3	1	1/5	1/7	0.085
12 months	5	5	1	1/5	0.236
24 months	7	7	5	1	0.630
Panel B: Most likely time required for defense readjustment to affect a turnaround in economy					
3 months	1	1/3	1/5	1/7	0.049
6 months	3	1	1/5	1/7	0.085
12 months	5	5	1	1/5	0.236
24 months	7	7	5	1	0.630
Panel C: Most likely time required for an adjustment to global competition can affect a turnaround in economy					
3 months	1	1	1/3	1/5	0.089
6 months	1	1	1/3	1/5	0.089
12 months	3	3	1	1/5	0.208
24 months	5	5	5	1	0.613

For each panel, which time period is more likely to indicate a turnaround if the relevant factor is the sole driving force?

Table 13.5 Most likely factor to dominate during a specified time period

	CA	R	Vector weights
Panel A: 3 Months			
CA	1	5	0.833
R	1/5	1	0.167
Panel B: 6 Months			
CA	1	5	0.833
R	1/5	1	0.167
Panel C: 1 Year			
CA	1	1	0.500
R	1	1	0.500
Panel D: 2 Years			
CA	1	1/5	0.167
R	5	1	0.833

Which factor is more likely to produce a turnaround during the specified time period?
CA conventional adjustment
R restructuring

Table 13.7, coupled with the mid-points of the alternate time periods to provide unbiased estimates:

2. At an annual percentage change in real gross national product of about 3.6%, the recovery would be "moderate" (using our range definition). Tables 13.8, 13.9, 13.10, 13.11 provide the relevant comparison matrices. Specifically, Table 13.11 documents the judgments regarding the strength of the expansion.

Table 13.6 The completed supermatrix

	C.A.	E.R.	Con.	Exp.	Inv.	Con.	F.P.	M.P.	F.S.	D.P.	G.C.	3 months	6 months	1 year	2 years
Conventional adjust	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.833	0.833	0.500	0.167
Economy restructuring	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.167	0.167	0.500	0.833
Consumption	0.118	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Exports	0.029	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Investment	0.058	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Confidence	0.334	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fiscal Policy	0.118	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monetary policy	0.343	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Financial sector	0.0	0.584	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Defense Posture	0.0	0.281	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Global competition	0.0	0.135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3 months	0.0	0.0	0.043	0.083	0.078	0.517	0.099	0.605	0.049	0.049	0.089	0.0	0.0	0.0	0.0
6 months	0.0	0.0	0.113	0.083	0.078	0.305	0.086	0.262	0.085	0.085	0.089	0.0	0.0	0.0	0.0
1 year	0.0	0.0	0.310	0.417	0.305	0.124	0.383	0.042	0.236	0.236	0.209	0.0	0.0	0.0	0.0
2 years	0.0	0.0	0.534	0.417	0.539	0.054	0.432	0.091	0.630	0.630	0.613	0.0	0.0	0.0	0.0

Table 13.7 The limiting supermatrix

	C.A.	E.R.	Con.	Exp.	Inv.	Con.	F.P.	M.P.	F.S.	D.P.	G.C.	3 mo.	6 mo.	1 yr.	2 years
Conventional Adjust	0.0	0.0	0.484	0.484	0.484	0.484	0.484	0.484	0.484	0.484	0.484	0.0	0.0	0.0	0.0
Economy Restructuring	0.0	0.0	0.516	0.516	0.516	0.516	0.516	0.516	0.516	0.516	0.516	0.0	0.0	0.0	0.0
Consumption	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.057	0.057	0.057	0.057
Exports	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.014	0.014	0.014	0.014
Investment	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.028	0.028	0.028	0.028
Confidence	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.162	0.162	0.162	0.162
Fiscal policy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.057	0.057	0.057	0.057
Monetary policy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.166	0.166	0.166	0.166
Financial sector	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.301	0.301	0.301	0.301
Defense posture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.145	0.145	0.145	0.145
Global competition	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.070	0.070	0.070	0.070
3 months	0.224	0.224	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6 months	0.151	0.151	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1 year	0.201	0.201	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2 years	0.424	0.424	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 13.8 Matrices for primary and subfactors for strength of recovery

Panel A: Which primary factor will be more influential in determining the strength of the recovery?

	CA	R	Vector weights
Conventional adjustment (CA)	1	1/5	0.167
Restructuring (R)	5	1	0.833

Panel B: Which subfactor is more important in influencing conventional adjustment?

	C	E	I	K	F	M	Vector weights
Consumption (C)	1	7	3	1	7	3	0.3117
Exports (E)	1/7	1	1/5	1/5	1	1/5	0.037
Investment (I)	1/3	5	1	1/3	1/3	1/5	0.099
Confidence (K)	1	5	3	1	7	3	0.305
Fiscal policy (F)	1/7	1	3	1/7	1	1/7	0.035
Monetary policy (M)	1/3	7	5	1/3	7	1	0.207

Panel C: Which subfactor is more important in influencing economic restructuring?[a]

	FS	DP	GC	Vector weights
Financial sector (FS)	1	1/5	1/3	0.105
Defense posture (DS)	5	1	3	0.637
Global competition (GC)	3	1/3	1	0.258

[a] CI = 0.037

Note to Tables 13.8, 13.9, 13.10, 13.11: The next example is a simple hierarchy as shown in Fig. 13.2 in which the derived weights in each level starting at the top are weighted by the weight of the corresponding factor in the level above used to compare the elements. The results are then added for each element to obtain its overall weight. The process is continued to the bottom level of the hierarchy.

13.5 Conclusion

This chapter has demonstrated how the Analytic Hierarchy Process can serve as an additional tool for macroeconomic forecasts. We have used the highly interesting and relevant case of the U.S. economy during its current economic cycle (in which structural change has been particularly important) as the specific context for our analysis. As noted earlier, this approach could easily be adopted for use in forecasts based initially on formal macroeconometric models (e.g. to make judgments on shifts in intercepts and changes in the value of exogenous variables).

With regard to our forecasts, in addition to presenting the somewhat contrarian view that a meaningful turnaround in the present economic cycle was then still some months in the future, we concluded that the next recovery would be substantially less strong than those of the past three decades. We viewed this as

Table 13.9 Matrices for relative influence of subfactors on strength of recovery (conventional adjustment)

	V	S	M	W	Vector weights
Panel A: Relative likelihood of the strength of recovery if consumption drives the expansion[a]					
Very strong (V)	1	1	5	7	0.423
Strong (S)	1	1	5	7	0.423
Moderate (M)	1/5	1/5	1	3	0.104
Weak (W)	1/7	1/7	1/3	1	0.051
Panel B: Relative likelihood of the strength of recovery if exports drives the expansion[b]					
Very strong (V)	1	1	1/3	1/5	0.095
Strong (S)	1	1	1/3	1/5	0.095
Moderate (M)	3	3	1	1/3	0.249
Weak (W)	5	5	3	1	0.560
Panel C: Relative likelihood of the strength of recovery if investment drives the expansion[c]					
Very strong (V)	1	1	1/3	2	0.182
Strong (S)	1	1	1/3	2	0.182
Moderate (M)	3	3	1	6	0.545
Weak (W)	1/2	1/2	1/6	1	0.091
Panel D: Relative likelihood of the strength of recovery if confidence drives the expansion[d]					
Very strong (V)	1	1	3	5	0.376
Strong (S)	1	1	3	5	0.376
Moderate (M)	1/3	1/3	1	7	0.193
Weak (W)	1/5	1/5	1/7	1	0.054
Panel E: Relative likelihood of the strength of recovery if fiscal policy drives the expansion[e]					
Very strong (V)	1	1	1/5	1	0.125
Strong (S)	1	1	1/5	1	0.125
Moderate (M)	5	5	1	5	0.625
Weak (W)	1	1	1/5	1	0.125
Panel F: Relative likelihood of the strength of recovery if monetary policy drives the expansion[f]					
Very strong (V)	1	1	1/5	1/3	0.084
Strong (S)	1	1	1/5	1/3	0.084
Moderate (M)	5	5	1	7	0.649
Weak (W)	3	3	1/7	1	0.183

For each panel, which intensity is more likely to obtain if the designated factor drives the recovery?
[a] C.I. = 0.028
[b] C.I. = 0.016
[c] C.I. = 0.0
[d] C.I. = 0.101
[e] C.I. = 0.0
[f] C.I. = 0.101

being fundamentally attributable to the dramatic restructuring of important sectors of the global economy.

Table 13.10 Matrices for relative influence of subfactors on strength of recovery (restructuring)

	V	S	M	W	Vector weights
Panel A: Relative likelihood of the strength of recovery if financial sector drives the expansion[a]					
Very strong (V)	1	1	1/3	1/5	0.095
Strong (S)	1	1	1/3	1/5	0.095
Moderate (M)	3	3	1	1/3	0.249
Weak (W)	5	5	3	1	0.560
Panel B: Relative likelihood of the strength of recovery if defense posture drives the expansion[b]					
Very strong (V)	1	1/3	1/5	1/7	0.055
Strong (S)	3	1	1/3	1/5	0.118
Moderate (M)	5	3	1	1/3	0.262
Weak (W)	7	5	3	1	0.565
Panel C: Relative likelihood of the strength of recovery if global competition drives the expansion[c]					
Very strong (V)	1	1	1/3	1/5	0.101
Strong (S)	1	1	1/3	1/5	0.101
Moderate (M)	3	3	1	1	0.348
Weak (W)	5	5	1	1	0.449

For each panel, which intensity is more likely to obtain if the designated factor drives the recovery?

[a] CI = 0.016

[b] CI = 0.044

[c] CI = 0.012

Table 13.11 Overall results for strength of recovery

	% GNP Growth	
Very strong	(5.5–6.5)	0.108
Strong	(4.5–5.5)	0.141
Moderate	(3–4.5)	0.290
Weak	(2–3)	0.461
% GNP recovery rate[a]		3.6

[a] % GNP recovery rate calculated using the relative strength of conventional adjustment and restructuring (See Table 13.7, Panel A). Each used to multiply midpoints of % GNP Growth and then summed

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Chapter 14
A New Macroeconomic Forecasting and Policy Evaluation Method

14.1 Introduction

The economy is often faced with a turn that is not to our liking, and we sometimes think it ought to be controllable by macroeconomic policy. While the spectrum of policies ranges from Keynesian "fine tuning" to using monetarist "rules," every action (or inaction) of the government is a policy. Because of this it is important that government policy makers be guided by appropriate empirical models. Unfortunately, there is considerable variation in the large numbers of econometric models that have been developed thus far. Moreover, there are persistent problems, both technical and theoretical, with these models.

We will show that the Analytic Hierarchy Process (AHP) is an effective method for forecasting the end effects of a given policy or set of policies, and for determining the resulting impact on important variables such as unemployment and inflation. The forecasts could be made using the judgments of leading economists, congressmen, and personnel from major federal agencies such as OMB, CEA, commerce, the Federal Reserve and the Treasury. One side benefit would be a clearer understanding and appreciation of the problem under consideration as viewed from these different perspectives. The analysis in this chapter reflects the economic climate of the early 1980s.

14.2 A Few Words about Existing Econometric Models

There are problems with currently existing econometric models. Some problems are purely technical in nature and arise from the statistical approach. For example, there is a need to determine the proper estimation technique for equations with lagged dependent variables and serially correlated error terms when these equations are embedded in a simultaneous system of equations. There has been steady

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progress in the development of these statistical models but their formalism does not yield satisfactory solutions.

Other problems with the current crop of econometric models are more serious. For instance, the presence of so many models, all differing significantly in their structure, raises the question about how to specify the type of model and the parameters. There is a yet more serious question common to virtually all econometric models that use time series data to estimate historical correlations between variables. The estimated coefficients that represent peoples', firms', and governments' behavior are typically presumed to be "structural" in nature-that is, they are assumed to be invariant with respect to changes in the economic environment and, in particular, to changes brought about by policy actions. But, instead of being constant, these coefficients are unstable and may account for "sudden, unpredictable shifts in behavioral relationships…" [2]. Economists using these models have responded by developing statistical techniques that allow the estimated parameters to drift at random rather than forcing them to be constant [4, 6]. This has resulted in forecasts of somewhat increased accuracy [12].

However, allowing for random parameters in the estimation process is at best a statistical device for coping with a more basic problem. A fundamental observation is that on the part of consumers only the parameters of utility functions are truly invariant with respect to changes in policy, while for firms the same is true only for the parameters of their production functions. All "Behavioral" coefficients in an individual's demand and supply functions depend, in some fashion, on more primitive parameters in his utility function and his perceived budget constraint. After all, demand functions are the result of the individual maximizing his utility subject to the restraint given by the perceived economic environment as embodied in his budget constraint. Any change in government policy alters the economic environment and leads to a change in the structure of the demand function as the individual responds to the changed incentives. The same general conclusions are true for firms' (and individuals') supply functions. As a result, the assumptions made in most econometric models that the estimated coefficients of the demand and supply functions are stable with respect to changes in policy are hard to defend. Sargent [9] discusses in detail the econometric consequences of these observations (which originated with Lucas [5]) for standard econometric models.

These considerations have two immediate implications. The first is that the "sudden, unpredictable shifts…in the coefficients" are no longer a puzzle. The instability is a manifestation of the fact that a forecasting model's coefficients are not truly structural in nature and, because of this, shifts and changes are to be expected. The second, and more serious, weakness is that standard econometric models are particularly unable to forecast results of alternative policies because as different policies are instituted the parameters of the estimated demand and supply functions change due to people and firms altering their behavior. In virtually all econometric models, this effect is simply ignored because of technical difficulties.

These defects of existing models have led to widely differing reactions among economists. Equilibrium theorists tend to regard the objections sympathetically while disequilibrium (Keynesian) economists tend to dismiss them as minor. Some, such as Sims [10], concluded that all existing macroeconomic models are misspecified and that economists can predict virtually nothing about the effects of different policies. Robert Lucas [5] bluntly wrote, "features which lead to success in short term forecasting are unrelated to quantitative policy evaluation…The major macroeconomic models are (well) designed to perform the former task only, and these models can, in principle, provide no useful information as to the actual consequences of alternative economic policies." Others, such as Anderson [1], have attempted to manipulate existing models to avoid the problems mentioned above. Still others, mostly the designers, users and sellers of large econometric models have ignored these criticisms or else dismissed them as trivial. The AHP, however, enables us to take account of these points and to include effects of the policies being considered in our forecasts.

14.2.1 First Stage Problem

We will consider the problem of finding the best macroeconomic policy package among a given set by considering the effect that each policy package has on national "welfare." The effect of each package on national welfare is, in turn, decomposed into the effects of the package on key criteria such as inflation, unemployment, and growth. In terms of the AHP, this problem formulation leads to a three level hierarchy. The goal of best policy for the national welfare is in the first level. The criteria occupy the second level and the policy packages occupy the third level. The hierarchy, corresponding to this problem from which the relative effectiveness of the different policies on the third level are determined, is illustrated later.

14.2.2 Second Stage Problem

In the second stage we incorporate both the uncertainty concerning the exogenous forces operating on the economy and the possibility that the effectiveness of the various policies may change over time. Uncontrollable forces that affect the economy are included in the hierarchy in another level that involves what we call "exogenous scenarios," or SE's. These SE's consist of elements beyond the control of the policymaker that are deemed to exert an important effect upon the economy. Examples of such elements are drastic changes in the real price of energy, or wars involving vital interests of the nation. Since these scenarios are by their nature uncertain, a number of potential scenarios are constructed. Moreover, time is intimately involved whenever a scenario is constructed, and the expected SE may change with the passing of time.

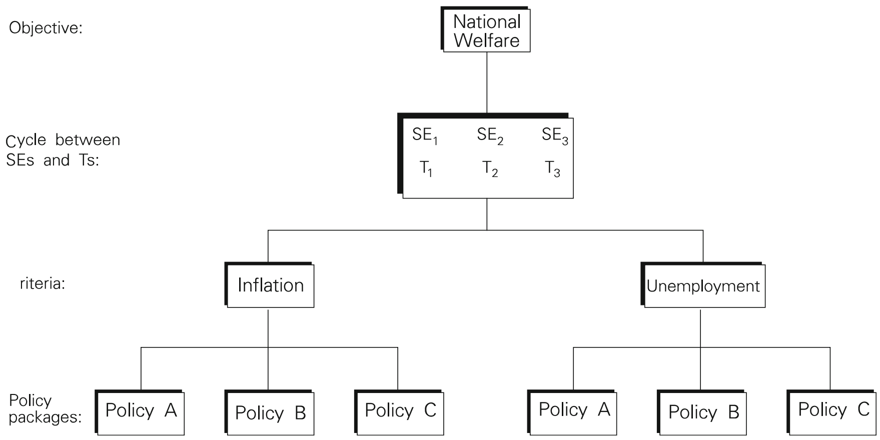

Fig. 14.1 Illustrative example, stage two problem

The hierarchy is a modification of that described above with a cycle between the projected scenarios and time appearing in level two and the rest of the hierarchy pushed down one level. Figure 14.1 presents the modified hierarchy. The cycles between the scenarios and the time periods are designed to give us the relative likelihoods of occurrence of the various SE's in the given time periods and also the relative importance of the time periods to the occurrence of the scenarios.

Using the AHP the likelihood of the occurrence of a given scenario in different time periods is calculated and for any given time period, the likelihood of each scenario actually occurring is obtained.

To find the priorities of both the time periods and the scenarios simultaneously a supermatrix is constructed (see [7]) for use of the supermatrix to solve cycling or feedback priority problems in the AHP). The two sets of eigenvectors which give the likelihood of the scenarios in each time period and the likelihood of occurrence of the scenarios across the time periods are used as the columns of two matrices. Each matrix occupies one of the two off-diagonal positions of a 2×2 super matrix which is column stochastic. The limiting power of the matrix yields the priorities of both the time periods and the scenarios. The priorities of the scenarios are used for subsequent weighting in the hierarchy.

Given these likelihoods, the next step in the procedure is to apply the familiar process of ranking the effectiveness of the policies with respect to the criteria. The only difference from the usual AHP composition concerns time. For each time period and exogenous scenario combination under consideration, the rankings are obtained from questions of the form: "Given exogenous scenario SE, how much more effective is policy P enacted at time T, than policy P, also enacted at time T, in lowering the unemployment rate at time T?" For each particular time period and exogenous scenario combination, the contribution of each policy toward the nation's welfare is computed precisely. For each particular time period, these welfare vectors are weighted by the likelihood of occurrence of the specific SE and

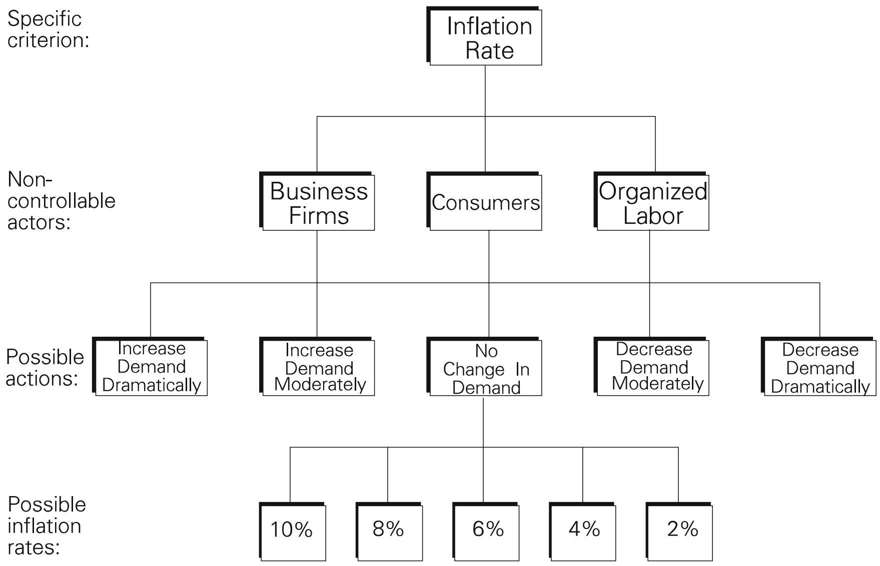

Fig. 14.2 The extended hierarchy with noncontrollable actors

the weighted vectors are summed to arrive at the overall expected relative contribution of the policies toward achieving the nation's welfare. Since each of these summed vectors applies to time periods somewhere in the future, they are discounted to the present to arrive at the overall effectiveness of the policies. One selects the policy with the largest priority.

14.2.3 Quantitative Forecasts

After the policies have been qualitatively ranked, the next step is to obtain the quantitative forecasts. We will illustrate our forecasting procedure by using only the first stage, short-run technique.

The forecasting procedure introduces a second hierarchy, which extends the first hierarchy further down, and adds a new element "non-controllable actors." Non-controllable actors are organizations, groups of individuals, or institutions who wield substantial influence over certain sectors or variables but who are not under the direct control of the policy maker. The non-controllable actors will occupy the second level in this hierarchy, immediately beneath each criterion. The level under the non-controllable actors will contain the range of actions they can take to influence the criteria. Immediately beneath this will be the level containing the quantitative effect each possible action could have on the criteria.

An example of this type of hierarchy is given in Fig. 14.2 for the criterion of inflation. The second row contains suggested non-controllable actors who exert direct influence on the inflation rate. It would be possible to include other groups who can influence the inflation rates but the three given in the figure will suffice for the purposes of this illustration. The first step would be to construct a comparison matrix between the three non-controllable actors and to calculate the relative influence each exerts upon the inflation rate.

The third level in Fig. 14.2 illustrates a range of possible actions consumers could take that would affect the inflation rate. There would be other analogous entries in this level for the other non-controllable actors. We have omitted them to simplify things. These five actions are grouped in a comparison matrix and ranked according to the question: “Given that whatever specific policy we are quantifying has been adopted, what is the likelihood that one of the actions (e.g., increase demand with moderate intensity, “moderately”) will occur relative to another action?” The weights obtained from this matrix will represent the relative likelihoods that consumers will change their demand for goods by the given intensity. The last level in the hierar-chy lists the range of possible inflation rates. Again, each entry in the “possible actions” level of the hierarchy will have associated with it a range of possible inflation rates. Again, for simplicity, we do not show all the detail. This level is prioritized in a comparison matrix by answering the question: “Given that the specific possible action has occurred, (e.g., no change in demand) what is the likelihood that inflation will assume a certain value as compared to another?” The weights obtained from this exercise will be the priorities that the inflation rate will be equal to the given amounts.

The next step is to obtain the quantitative forecast. This is done by first weighting the possible inflation rates by the priority of their occurrence for each possible action. These expected inflation rates are then weighted by the likelihood that the possible action to which they pertain takes place. For example, the expected inflation rate, given that there is no change in demand by consumers, might be 7%. This figure is, in turn, weighted by the priority that there is no change in demand by consumers. When this has been done for each of the possible actions by consumers, the (five) weighted figures are summed to arrive at the expected value of the “consumer’s contribution” to the inflation rate. This procedure is carried out for all other non-controllable actors being considered. The final step is to weight each non-controllable actor’s expected contribution by the relative importance of the actor to arrive at the overall expected inflation rate. This procedure is implemented for all the criteria to be forecast for all the specific policies being considered.

There are several useful points to make about this approach. First, in other cases in which forecasting has actually been carried out, the results have proven to be accurate by other measures (See Zahedi [11] for forecasting applications). In addition, when forecasting, each comparison matrix is based on the specific policy considered. The question used to rank the possible actions refers directly to the policy package for which the forecast is being made. It is at this stage that we allow the non-controllable actors to react differently according to whatever policy we are considering. Thus we take into account the criticism of Lucas and others that the behavior of economic agents depends strongly upon the policies that are in force.

Finally, the use of the AHP, combined with judgment based comparisons eliminates the complaint levied against econometric models that the results of policy exercises are predetermined by the model‘s basic structure. The AHP is sufficiently general so that it is possible to include a variety of non-controllable actors in an effort to capture effects neglected by specific models and modelers. Economists belonging to the monetarist school tend to dismiss the effect that organized labor has on the inflation rate. If it were a monetarist economist using the AHP to forecast the inflation rate, it would still be possible to include labor unions in the series of non-controllable actors—the monetarist would simply give it a small weight.

14.3 Application of the AHP to Macroeconomic Policy

We examine the problem of selecting the best macroeconomic policy package in a given set of policy packages by considering the effect that each policy package has on national "welfare." In our example, we assume that national welfare is affected by five key criteria: the inflation rate, the unemployment rate, the economic growth rate, the level of domestic stability and the state of foreign relations. The economic criteria have the usual meanings. Inflation pertains to a general increase in prices as measured by, for example, the GNP deflator; unemployment refers to the percentage of the labor force unemployed; and economic growth refers to increased per capita real GNP. In our example, we define the reduction in inflation to be a four percentage point reduction; the reduction in unemployment meant a one percentage point reduction; and the increase in growth referred to a one half of a percentage point increase. The last two (noneconomic) criteria are not expressed quantitatively and could be defined at the start of the exercise to suit specific requirements. We also define domestic stability to include racial integration, political participation, and business-labor–government relations. The criterion of foreign relations included relations with allies, the Third World, the oil producing Middle East, and the Soviet/Communist nations.

There are two features to note in the list of criteria. First, the set is not exhaustive. It would be possible to add or delete criteria depending on the views of the user. The indeterminancy resulting from what must be a normative listing of criteria for the objective function is not specific to the AHP but is common to *all* methods of evaluating alternative policies. The second feature is that the inclusion of domestic stability and foreign relations in the list of criteria serves to demonstrate the flexibility of the AHP to combine unlike factors in the decision-making process. Though the above two criteria are not immediately economic, it seems clear that the level of national welfare is influenced by the state of foreign relations and domestic stability. To this extent, the scope of this model is potentially much broader than conventional ones.

In the level below the criteria we have the policy packages. Thus this problem is a three level hierarchy. The overall objective, national welfare, is at the top of the

Table 14.1 Contribution of the criteria to the overall objective (national welfare)

National welfare	I	U	G	D	F	Weights
Inflation	1	3	5	4	6	0.45
Unemployment	1/3	1	4	4	6	0.30
Growth	1/5	1/4	1	2	2	0.11
Domestic stability	1/4	1/4	1/2	1	2	0.09
Foreign relations	1/6	1/6	1/2	1/2	1	0.05

hierarchy. The criteria occupy the second level and the policy packages, to be evaluated for how they affect each criterion, are in the bottom level.

In our example, we took the vantage point of a "representative" person in society to provide judgments for the pairwise comparisons of the criteria with respect to their importance to national welfare. It should be emphasized once again that *any* attempt through any model to develop economic policy must specify implicitly or explicitly an objective function for that policy. Either way such an objective function will rely on value judgments. Thus, establishing the relative importance of the criteria in level one for a "representative" person in society amounts to specifying explicitly the objective function and the value judgments leading to it. The result is the vector of relative weights, or the relative importance of the criteria to national welfare, given in Table 14.1. Note that a reduction in the inflation rate is deemed the most important action to improve national welfare. A reduction in unemployment, while not as important as a reduction in the inflation rate, is still more important than the remaining criteria. The other criteria have very low priorities in comparison with inflation and unemployment. The values in this vector of relative weights can be interpreted either as the importance of one criterion over another, e.g., inflation is nine times (0.45/0.05) as important as foreign relations, or as the relative attention that should be paid a particular criterion (inflation = 45%) in attempting to improve national welfare.

The next level of the hierarchy involves specifying policy packages and forecasting their effect upon each of the five criteria. Various new and traditional macropolicies were selected, 20 in all. For simplicity, the policies were clustered into three sets "A", "B", and "C", corresponding to what is generally regarded as "conservative," "moderate" and "liberal" respectively. The policy packages were evaluated with respect to the economic criteria (inflation, unemployment and growth), three times–from the vantage point of a monetarist, from that of a Keynesian and, finally, from a "supply-side" viewpoint. For the criteria of domestic relations and foreign relations we evaluated the impact of the policy packages from the point of view of a "representative" individual again; it was not necessary to distinguish among monetarist, Keynesian, and supply-sider opinions. We then selected the optimal policy from each set (A, B, and C) for each economic viewpoint, combined the optimal policies into a single set and selected the best overall policy for each school.

The policies were evaluated only for their presumed short-run effect on the five criteria. And we took into consideration the constraint that the government's budget places on the use of various policy tools. For example, if the government

Table 14.2 Symbols for the description of policies

G	Government spending
B	Issuance of bonds
M	Issuance of money
Tx	Total tax rates (Corporate and personal)
Tc	Corporate tax rates
Gm	Military spending
Gtr	Transfer payments
↑	Increase
↓	Decrease

Examples of the notation
(1) Tx↓,B, M↑ implies a decrease in tax rates of 10% with any revenue shortfall made up by increasing, in the same proportion as they stood before the tax cut, the amount of bonds and money issued
(2) Gtr↑(lO%) = G↓ implies a 10% increase in total Transfer payments that is offset by an equal decline in government spending on defense
In general, the given percentage change applies to the first item in the policy list. The only exception to this is the policy package denoted by G, Tx, M↓ where the percentage decrease applies to the first two entries in the string and the change in M is the balancing residual

Table 14.3 Evaluation of cluster B policies with respect to inflation (Monetarist viewpoint)

Inflation 0.45 (%)	10% Tx↓,B, M↑	5% Tx↓,B, M↑	10% G,Tc↓	5% G,Tc↓	Relative weights
Tx↓,B, M↑ 10	1	1/6	1/7	1/5	0.044
Tx↓,B, M↑ 5	6	1	1/7	1/5	0.115
G,Tc↓ 10	7	7	1	3	0.560
G,Tc↓ 5	5	5	1/3	1	0.281

lowers tax rates by 10% while leaving its total spending unchanged, there would be a potential shortfall of revenue. If this were the case, either bonds and/or money would have to be issued to finance the tax cut and to reconcile expenditures with revenues. Thus, in the following development, we specified complete policies (e.g., "lower tax rates by 10 percent and issue money to cover any shortfall"). The notation and symbols to describe the policies are given in Table 14.2.

In Table 14.3, the evaluation of cluster B policies with respect to inflation from the monetarist viewpoint, we give an example of how we evaluated cluster policies through pairwise comparisons with respect to a criterion. Similar comparisons were carried out for every economic group and every cluster. The judgments were given in response to the following type of question: "From a monetarist viewpoint, how much more effective in reducing the inflation rate will be a policy of decreasing tax rates by 10% while balancing the budget using money and bonds

Table 14.4 Determination of the overall effectiveness of the policy (G, Tx, M↓ 10%) (Monetarist viewpoint)

Objective A	Weight of the criterion B	Weight of the policy with respect to the criterion C	Contribution to the overall criterion D = B × C
Inflation	0.450	0.120	0.05
Unemployment	0.300	0.103	0.03
Growth	0.110	0.306	0.03
Domestic stability	0.090	0.240	0.02
Foreign relations	0.050	0.099	0.01

Overall effectiveness 0.14

(i.e., Tx↓, B, M↑ 10%) than will be a policy of cutting tax rates by five and issuing money and bonds to make up any revenue shortfall (i.e., Tx↓, B, M↑ 5%)?" In this case, where the policies are ranked from a monetarist perspective, we judged the second policy to be between strongly and very strongly more effective (i.e., 6) than the first policy. Since the comparison is, by convention, between the *first* policy relative to the *second* policy, we placed the ranking (1/6) in the matrix. The remaining comparisons in this matrix were entered in a similar fashion. The extreme right column gives the vector of relative weights for these four policies to achieve a reduction in inflation.

Once the policy matrices are prioritized with respect to each of the five criteria, the overall efficacy of each policy is determined by multiplying the effectiveness of each policy with respect to a given criterion by the weight of the criterion toward affecting national welfare, and then adding over all the criteria.

An example of this procedure is given in Table 14.4. In this table we calculated the overall effectiveness of policy (G, Tx, M↓ 10%) when judged from a monetarist viewpoint. Column 2 gives the weights of the criteria we developed in Table 14.1. Column 3 reports how effective this particular policy is in satisfying the various criteria. The fourth column weights the effectiveness of the policy. These weighted contributions are summed and the overall effectiveness of the policy is given in the bottom row of the table.

Now we have an initial sorting of the 20 policies. The next step is to select the most effective policies from each cluster and then rank them directly against each other to find the overall best policy (Tables 14.5–14.7). The technique of clustering the policies into three groups, calculating the rankings within the groups and then calculating the rankings between the most effective policies within the groups might appear to involve more work than directly comparing all 20 potential policies simultaneously. This is, however, not the case as a simple calculation will show. Each comparison matrix involves n(n − 1)/2 judgments for the pairwise comparisons where n is the number of elements being compared. Our clustering method of evaluating policies required a total of 360 comparisons for each viewpoint. Directly comparing all the policies would have required 500

Table 14.5 Overall effectiveness of policies in cluster A[a]

Policies (%)	Overall effectiveness		
	Monetarist viewpoint	Keynesian viewpoint	Supply side viewpoint
$G,Tx,M\downarrow$ 10	0.14	0.10	0.35
$G,Tx,M\downarrow$ 5	0.11	0.11	0.19
$G\downarrow$ 10	0.11	0.11	0.16
$G\downarrow$ 5%	0.09	0.10	0.11
$G_M\uparrow = G_{TR}\downarrow$ 10	0.08	0.18	0.04
$G_M\uparrow = G_{TR}\downarrow$ 5	0.08	0.16	0.04
$M, G\downarrow$ 6	0.25	0.14	0.07
$M, G\downarrow$ 3	0.16	0.10	0.05

(%)	Inflation (0.45)			Unemployment (0.30)			Growth (0.11)			Domestic	Foreign
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(0.09)	(0.05)
$G,Tx,M\downarrow$ 10	0.120	0.107	0.283	0.103	0.030	0.469	0.306	0.061	0.487	0.240	0.099
$G,Tx,M\downarrow$ 5	0.069	0.119	0.196	0.185	0.139	0.225	0.124	0.117	0.191	0.103	0.047
$G\downarrow$ 10	0.072	0.144	0.171	0.136	0.026	0.155	0.219	0.064	0.158	0.177	0.065
$G\downarrow$ 5	0.034	0.089	0.134	0.149	0.110	0.078	0.124	0.156	0.077	0.164	0.033
$G_M\uparrow = G_{TR}\downarrow$ 10	0.014	0.089	0.021	0.159	0.299	0.015	0.026	0.265	0.018	0.044	0.351
$G_M\uparrow = G_{TR}\downarrow$ 5	0.014	0.045	0.022	0.170	0.299	0.015	0.023	0.291	0.014	0.108	0.188
$M, G\downarrow$ 6	0.457	0.254	0.100	0.033	0.019	0.026	0.102	0.017	0.033	0.087	0.141
$M, G\downarrow$ 3	0.220	0.153	0.072	0.065	0.078	0.019	0.058	0.029	0.022	0.076	0.078

(1): Monetarist Viewpoint, (2): Keynesian Viewpoint, (3): Supply Side Viewpoint
[a] The top part of table lists the overall effectiveness of the policies in Cluster A. The bottom part lists the effectiveness of the policies with respect to the specific criteria

comparisons. Thus, the clustering technique requires only 72 percent of the comparison needed by the direct method. Professor Patrick Harker [3] of the Wharton School has developed a procedure for making an even smaller number of comparisons.

For each school of thought we selected the two best policies from cluster A and cluster C and the single best policy from cluster B. We then used the AHP methodology to rank these policies to arrive at the "optimal" policy. Tables 14.8, 14.9, and 14.10 contain the results of this procedure for policies favored by monetarists, Keynesians, and supply-siders respectively.

14.4 Conclusion

Monetarists consider a policy to reduce the growth rate of the money supply by 6% matched by a decrease in government spending to be optimal. Keynesians find a policy of increasing government spending by 10% while financing the deficit by

Table 14.6 Overall effectiveness of policies in cluster B[a]

Policies (%)	Overall effectiveness		
	Monetarist viewpoint	Keynesian viewpoint	Supply side viewpoint
Tx↓, B, M↑ 10	0.20	0.29	0.41
Tx↓, B, M↑ 5	0.15	0.19	0.10
Tc, G↓ 10	0.40	0.34	0.38
Tc, G↓ 5	0.25	0.19	0.31

(0.05)	Inflation (0.45)			Unemployment (0.30)			Growth (0.11)			Domestic	Foreign
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(0.09)	(0.05)
Tx↓, B, M↑ 10%	0.040	0.073	0.330	0.509	0.590	0.602	0.103	0.583	0.580	0.151	0.109
Tx↓, B, M↑ 5%	0.115	0.129	0.116	0.245	0.252	0.068	0.073	0.261	0.080	0.076	0.250
Tc, G↓ 10%	0.560	0.550	0.421	0.093	0.050	0.273	0.544	0.069	0.287	0.490	0.418
Tc, G↓ 5%	0.281	0.247	0.133	0.154	0.107	0.057	0.280	0.087	0.053	0.283	0.223

(1): Monetarist Viewpoint, (2): Keynesian Viewpoint, (3): Supply Side Viewpoint

[a] The top part of table lists the overall effectiveness of the policies in Cluster B. The bottom part lists the effectiveness of the policies with respect to the specific criteria

issuing bonds and money to be the best policy. Supply-side economists favor a policy to reduce government spending and tax rates by 10% and would allow change in the money supply to be a balancing factor in the government's budget constraint.

It is interesting to see what we can observe about this analysis from the hindsight of our early 1987 perspective. Probably the best we can say is that a mixed set of policies prevailed. There was a supply-sider in the White House (Ronald Reagan) and something of a monetarist (Paul Volcker) holding the reins at the Fed. Taxes *were* decreased; inflation has moderated significantly; growth in the economy has been modest but steady since late 1982. However, it has not been possible to restrain government spending, thought by both monetarists and supply-siders in 1981 to be a very desirable end to achieve. This was the result primarily of an impasse between Congress and the Administration as to where to make the cuts—defense or social programs. (The recently enacted Gramm-Rudman legislation seeks to address this problem by annual across-the-board cuts if agreement is not forthcoming). There has accordingly been a tremendous rise in the budget deficit and in the trade deficit; unemployment, a goal though still high relative to the earlier post-war period, has been brought under control; interest rates are down significantly; the stock market has more than doubled from a Dow Jones Index of less than 1000 to over 2000. Whether this signifies a healthy economy remains to be seen and is probably dependent on one's point of view. The average U.S. citizen may consider himself to be better off than he was in 1981, but to those outside the U.S., we are living on borrowed money—to finance our trade and budget deficits.

Table 14.7 Overall effectiveness of policies in cluster C [a]

Policies (%)	Overall effectiveness		
	Monetarist viewpoint	Keynesian viewpoint	Supply side viewpoint
G, B, M↑ 10	0.15	0.20	0.12
G, B, M↑ 5	0.11	0.11	0.13
G, Tx, B, M↑ 10	0.07	0.16	0.05
G, Tx, B, M↑ 5	0.09	0.12	0.08
$G_{TR}\uparrow = G_M\downarrow$ 10	0.14	0.07	0.21
$G_{TR}\uparrow = G_M\downarrow$ 5	0.15	0.12	0.25
$G_{TR}\uparrow = Tc\uparrow$ 10	0.15	0.07	0.05
$G_{TR}\uparrow = Tc\uparrow$ 5	0.12	0.12	0.09

(%)	Inflation (0.45)			Unemployment (0.30)			Growth (0.11)			Domestic	Foreign
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(0.09)	(0.05)
G,B, M↑ 10	0.016	0.028	0.095	0.410	0.420	0.158	0.057	0.329	0.113	0.176	0.080
G,B, M↑ 5	0.028	0.043	0.135	0.225	0.122	0.114	0.081	0.231	0.159	0.131	0.153
G,Tx,B, M↑ 10	0.052	0.096	0.041	0.095	0.282	0.028	0.057	0.165	0.039	0.107	0.088
G,Tx,B, M↑ 5	0.101	0.170	0.073	0.082	0.079	0.064	0.031	0.119	0.057	0.054	0.235
$G_{TR}\uparrow = G_M\downarrow$ 10	0.263	0.141	0.220	0.035	0.030	0.272	0.118	0.043	0.225	0.052	0.046
$G_{TR}\uparrow = G_M\downarrow$ 5	0.263	0.232	0.303	0.039	0.018	0.249	0.102	0.043	0.319	0.073	0.060
$G_{TR}\uparrow = Tc\uparrow$ 10	0.108	0.076	0.037	0.055	0.030	0.033	0.455	0.023	0.025	0.264	0.222
$G_{TR}\uparrow = Tc\uparrow$ 5	0.171	0.208	0.090	0.066	0.015	0.082	0.027	0.027	0.054	0.144	0.125

(1): Monetarist viewpoint, (2): Keynesian viewpoint, (3): Supply side viewpoint

[a] The top part of table lists the overall effectiveness of the policies in Cluster C. The bottom part lists the effectiveness of the policies with respect to the specific criteria

Table 14.8 Overall effectiveness of monetarist policies[a]

Policy (%)					Overall effectiveness
M, G↓ 6					0.33
M, G↓ 3					0.18
Tc, G↓ 10					0.17
G, B, M↑ 10					0.18
G_{TR}↑ = G_M↓ 5					0.14
(%)	Inflation (0.45)	Unemployment (0.30)	Growth (0.11)	Domestic (0.09)	Foreign (0.05)
M, G↓ 6	0.595	0.063	0.230	0.075	0.212
M, G↓ 3	0.240	0.136	0.147	0.049	0.153
Tc, G↓ 10	0.113	0.159	0.503	0.184	0.061
G, B, M↑ 10	0.026	0.411	0.061	0.116	0.543
G_{TR}↑ = G_M↓ 5	0.025	0.231	0.059	0.576	0.030

[a] The top part of the table lists the overall effectiveness of the policies preferred by monetarists. The bottom part lists the effectiveness of the policies with respect to the specific criteria. Policies in this table were evaluated from a monetarist perspective

Table 14.9 Overall effectiveness of Keynesian policies[a]

Policy (%)					Overall effectiveness
G_M↑ = G_{TR}↓ 10					0.19
G_M↑ = G_{TR}↓ 5					0.11
Tc, G↓ 10					0.22
G, B, M↑ 10					0.26
G, Tx, B, M↑					0.20
(%)	Inflation (0.45)	Unemployment (0.30)	Growth (0.11)	Domestic (0.09)	Foreign (0.05)
G_M↑ = G_{TR}↓ 10	0.278	0.068	0.086	0.100	0.472
G_M↑ = G_{TR}↓ 5	0.143	0.093	0.102	0.223	0.259
Tc, G↓ 10	0.433	0.037	0.046	0.107	0.040
G, B, M↑ 10	0.057	0.522	0.317	0.365	0.114
G_{TR}↑ = G_M↓ 10	0.025	0.231	0.059	0.576	0.030

[a] The top part of the table lists the overall effectiveness of the policies preferred by Keynesians. The bottom part lists the effectiveness of the policies with respect to the specific criteria. Policies in this table were evaluated from a Keynesian perspective

In any event we have now shown how the AHP can be applied to the problem of selecting an optimal macroeconomic policy and estimating its impact.

This approach to forecasting has some advantages over more conventional methods. For instance, it makes it possible to incorporate ideas or theories into forecasts that are difficult to include in quantitative econometric models. In addition, since the AHP procedure is essentially "structure- free," it eliminates the criticism that the results obtained from its use are predetermined by its a priori

Table 14.10 Overall effectiveness of supply-side policies[a]

Policy (%)	Overall effectiveness
G, Tx, M↓ 10	0.33
G, Tx, M↓ 5	0.18
Tx↓, B, M↑ 10	0.17
G_{TR}↑ = G_M↓ 10	0.18
G_{TR}↑ = G_M↓ 5	0.14

(%)	Inflation (0.45)	Unemployment (0.30)	Growth (0.11)	Domestic (0.09)	Foreign (0.05)
G, Tx, M 10	0.562	0.536	0.567	0.116	0.161
G, Tx, M 5	0.232	0.157	0.156	0.121	0.261
Tx, B, M 10	0.126	0.239	0.211	0.193	0.433
GTR = GM 10	0.029	0.040	0.030	0.346	0.048
GTR = GM 5	0.051	0.028	0.037	0.224	0.097

[a] The top part of the table lists the overall effectiveness of the policies preferred by supply-side economists. The bottom part lists the effectiveness of the policies with respect to the specific criteria. Policies in this table were evaluated from a supply-side perspective

specification. Our brief analysis shows that the optimal choices of the various schools can be predicted by this process. The AHP also shows how strongly each ranks alternative policies relative to their primary preferences.

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Chapter 15
A New Approach to the Middle East Conflict: The Analytic Hierarchy Process

15.1 Introduction

We present an alternative process to address the Israeli Palestinian conflict. It does so in two ways that are different from past efforts. The first is by formally structuring the conflict and the second is the manner in which discussions are conducted and conclusions drawn.

The approach will help create a solution to the conflict and provide negotiators with a unique pathway to consider the thorny issues and corresponding concessions underlying the deliberations, together with their implementation. Among the prior contentious issues addressed by this process and encouraged by governments and major participants in the conflicts were the difficult confrontations in South Africa and in Northern Ireland. The outcomes of this process added valuable dimension to the discussions and resolutions of those problems.

The Middle East conflict is a prolonged and interminable struggle between parties deeply committed to unyielding positions related to identity, religion and territory. Understanding the Israeli–Palestinian conflict necessitates the understanding and recognition that both parties believe there is a theological bond between their people and the land. In addition, all three major religions recognize Jerusalem as symbolic of their belief in a one god idea.

The severity of this conflict has intensified in our life-time because international events have catapulted the Middle East into a crucial position in the world's search for peace. Claims are made by these peoples of their right to have a state that ensures their group identity. The problem is greatly compounded by great power rivalries, weapon sales, interference by neighboring countries, economic and social discrepancies and the threat of nuclear retaliation. Although it is possible that the global framework might accelerate a solution, in fact, it complicates the solution due to the apparent insolvability of the issues. Hence, a solution continues to elude the global community.

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Some of the world's best negotiators, diplomats and able leaders have grappled with the resolution of this conflict. However, despite their best efforts, the current condition continues to torment all the parties. Since the inception of the Analytic Hierarchy Process and its generalization to dependence and feedback, the Analytic Network Process (ANP), authors have conducted numerous case studies (e.g. [1–3]) that suggest the method as an alternative approach to conflict resolution that will lay bare the structure of the problem and allow reasoned judgment to prevail.

Nonetheless, when one deals with conflict, especially conflict of a prolonged duration, reason rarely prevails. In fact, with respect to the conflict between the Palestinians and the Israelis, positions have become entrenched and each party seeks not only to satisfy its own needs but also does not mind increasing the costs of concessions made by the other party. This type of conflict is defined as retributive (Saaty 1986) because of its prolonged negative emotional content. Retributive responses differ from the usual cooperative conflicts in which the parties work for a win–win outcome, by their partly malevolent intentions, whereby the parties do not care about the losses of the other side.

In most long-lasting conflicts, each party's grievances increase while the concessions they are willing to make decline in number, quality, and perceived value. Both parties lose sight of what they are willing to settle for, generally exaggerate their own needs, and minimize the needs of the other side over time. The concessions worth trading versus the concessions the other party is willing to trade become more indefinite and less concise. But, it is precisely the matter of trading that needs to be made more concrete and of higher priority for both sides, if a meaningful resolution is to be found.

Without a formal way of trading off the concessions and packages of concessions, both sides are likely to suspect that they are getting the short end of the bargain. After the parties have agreed to a trade, very specific binding language about the terms of the agreement, clear implementation policies and outside guarantors are needed. The worth of the concessions traded, as perceived by both the giver and receiver, need to be accurately determined and recorded. All of this requires going beyond verbal descriptions of the concessions to more broadly include their economic, social, geographic, humanitarian and historical worth. It is critical that all of this needs to be translated into priorities derived in terms of the different values and beliefs of the parties. Priorities are universal and include the diversity of measures in terms of which economic, social and other values are measured. The Analytic Hierarchy Process (AHP) provides a way to perform such an assessment with the participation of negotiators for the parties. It is a positive approach that makes it possible to reason and express feelings and judgments with numerical intensities to derive priorities.

With the assistance of the panel of Israeli participants and Palestinian participants, AHP has now been applied for the first time with the input of representatives of both sides who were knowledgeable and informed about the issues associated with the Palestinian–Israeli conflict. They obviously did not represent the full spectrum of political ideas and notions. The process makes it clear that moderation in different degrees by both sides is essential to arrive at acceptable agreements on concessions proposed and agreed upon by both sides. AHP makes it possible to evaluate moderate and extreme viewpoints and determine their effect on the trading of concessions. The results obtained encourage us to advocate its use in this negotiation process.

We need to begin by emphasizing that the outcome of our effort is the beginning of an elaborate undertaking to produce a viable solution to the Israeli–Palestinian conflict. It is simply a novel framework for dialogue. A differentiation from other approaches is its potential to minimize the influence on the outcome of much of the intense emotions that have usually accompanied such discussions. The framework forces the negotiators to approach the issues using a quantitatively oriented set of judgments to compare and tradeoff various issues, benefits, costs and concessions in a way in which each individual item is separated from the influences of other passionately charged items. We acknowledge that in an emotionally charged conflict such as this, there will inevitably remain a residual emotionality and feelings that cannot be ignored and inevitably affect the judgments. This does not affect the viability of the process, because the numerical representation of the judgments allows for such variability up to a limit that can be measured. It essentially allows one to decompose the problem into smaller components that can be dealt with more easily. While judgments may vary according to the perceived power of the parties, the essential nature of the process is not compromised, unless participants are influenced to change their judgments.

15.2 Developing a Comprehensive Approach

One might ask: Why is it that so many distinguished politicians and negotiators have failed to reach consensus after 60 years of trying? Here are some possible reasons:

1. They had no way to measure the importance and value of intangible factors which can dominate the process.
2. They had no overall unifying structure to organize and prioritize issues and concessions.
3. They had no mechanism to trade off concessions by measuring their worth.
4. They had no way to capture each party's perception of the other side's benefits and costs.
5. They had no way to provide confidence for the other party that the opposing party is not gaining more than they are.
6. They had no way to avoid the effect of intense emotions and innuendoes which negatively affect the negotiation process.
7. They had no way to test the sensitivity and stability of the solution to changes in their judgments with respect to the importance of the factors that determined the best outcome.

It is not a coincidence that the Analytic Hierarchy Process addresses each of these reasons in a comprehensive and deliberate way, thus eliminating many of the obstructions for moving forward to identify an equitable final solution.

15.3 The Process

The AHP is about breaking a problem down and then aggregating the solutions of all the sub-problems into a conclusion. It facilitates decision making by organizing perceptions, feelings, judgments, and memories into a framework that exhibits the forces that influence a decision. In the simple and most common case, the forces are arranged from the more general and less controllable to the more specific and controllable. The AHP is based on the innate human ability to make sound judgments about small problems and also about large problems when a structure like a hierarchy can be built to represent the influences involved. It has been applied in a variety of decisions and planning projects in nearly 40 countries.

Briefly, we see decision making as a process that involves the following steps:

(1) Structure a problem with a model that shows the problem's key elements and their relationships
(2) Elicit judgments that reflect knowledge, feelings, or emotions of the primary parties, as well as all other parties that have influence on the outcome
(3) Represent those judgments with meaningful numbers
(4) Use these numbers to calculate the priorities of the elements of the hierarchy
(5) Synthesize these results to determine an overall outcome
(6) Analyze sensitivity to changes in judgment

The retributive conflict resolution approach presented here takes into consideration the benefits to A from concessions by B and the costs to A of the return concessions A makes, as well as A's perception of the benefits to B from the concessions A makes, and also A's perception of the costs to B of the concessions B makes. A similar consideration is made for B. Findings from this exercise suggest that the development of "bundles" of concessions may minimize the difference in ratios of gains and losses between the two parties that a negotiator can use as a tool to move the resolution process forward.

The expressed objectives of the study were:

- To identify the issues, major and minor and to examine the relative significance or priority of the issues currently inhibiting solution of the Israeli–Palestinian conflict
- To share knowledge and insights about the current Israeli–Palestinian situation from differing points of view
- To construct a comprehensive model of the situation
- To explore the benefits and costs of alternative courses of action

The traditional approach involving diplomacy and face to face negotiations has led to an inconclusive outcome, partially attributable to attitudes colored by strong emotions on both sides. Our approach attempts to address the impact of negative attitudes by focusing the participants on making judgments that measure the intensity of their perceptions about the influences that each of the issues brings to bear upon the final outcome.

In this study we consider each party's list of issues, which if addressed by the other party by making concessions, would provide sufficient benefit to that side towards meeting their goal. They, in turn, would be willing to make concessions to the other side to balance those concessions with an equivalent tradeoff. We refer to these issues as criteria. The process consists of taking a set of concessions from one side and measuring them against these criteria in terms of actual or perceived benefits to the other side. Actual benefits (or costs) are defined as judgments by one party about the relative importance of the concessions they receive (or give). Perceived benefits (or costs) are defined as putting oneself in the shoes of the other side to estimate the benefits (or costs), even though that side may have a totally different opinion about what the concessions received or offered are worth.

The remainder of this work is structured as follows: In the next section we define the problem in general terms. Subsequently we outline the structure of the decision in the form of multiple hierarchies. This effect is evaluated by the parties according to their value systems, both actual and perceived. The outcomes of this analysis are priorities used to assess ratios of gains and losses by both sides that make it possible to determine those concessions for which each party's gains exceed its losses and these gains to losses are not unacceptably large for either party in comparison with the other party. Then we examine and identify ratios that are nearly equal for the two sides from the concessions made, and pose questions about the viability of such bundles of concessions that are traded off. Finally we suggest a way for moving the process to the next level through better definition of the issues and concessions as well as through recognition of potential implementation policies and other relevant changes.

15.4 Implementing the process

In the opening day of the 3 day meeting the panel brainstormed the issues and structured the problem, defined the parties at interest and developed a series of concessions that each party might offer to the other.

The process was not without conflict and negotiation of its own. At times, the panel made judgments without agreement on exact definitions. There was nearly always unanimous agreement on the nature of the conflict, with much debate about the underlying concerns. These concerns differed according to which constituent group was putting them forward. For example, among the Palestinian key constituents are Palestinian refugees, Hamas followers, Fatah followers, Palestinians who still live in Israel and Diaspora Palestinians. Among the Israeli constituents are the ultra right orthodox community, Israelis living in settlements in the West Bank, those associated with the Likud movement, those associated with the Labor Party, and those more actively seeking peace as a primary objective, without dwelling on the details of the difficulties to achieve it.

Since the beginning of the conflict, different constituents have proposed many different approaches. These approaches inevitably influenced the panel's perception of the concessions to be made by either side. In fact, one participant suggested that it would be difficult "to think outside the box." He thought that the group was so influenced by previous thinking that they would have difficulty in conceptualizing 'creative' alternatives that had not been proposed previously.

The panel defined the goal as an attempt to understand what forces and influences or combinations thereof would tend toward a consensus peace accord for the conflict between Israel and the Palestinians. To accomplish this goal, the panel of nine individuals was assembled to represent a cross section of thinking on both sides. Its members had present or prior experience in academia, government and in business. However, it was recognized that the panel did not represent a complete cross-sample of opinions. The sample of panel participants was not sufficiently large to include all points of view nor was it intended to be so because of limitations of time and resources.

This initiative only sought to test the AHP methodology on a problem that had previously evaded resolution. The size of the panel was thought to be sufficient to account for the different populations. However, it was agreed that the work is exploratory in nature and intended to demonstrate how the method can be used over a short period of time to arrive at a process that moves the negotiation process forward.

As mentioned above, at no point in the development and evaluation of the problem was the process easy. In fact, even the "purpose" was not easily agreed upon and at several points in the 3 days over which the meetings took place, the panel readdressed what the undertaking was intended to accomplish. It looked at the purpose of the project from various perspectives in the hope of finding one that appeared more promising than others that have been tried. The panel brainstormed all the issues they could think of that had to be considered in the framework. They are listed in Table 15.1 below as they were identified by the participants and later organized into categories with no attempt to eliminate possible duplications. Listing the issues made it easier to identify the concessions, and to structure the problem. Taking time to structure the problem in as comprehensive a fashion as may be feasible, is a crucial first step before attempting to prioritize the relative importance of its constituent parts that have causal influence on the concessions and actions to be taken. Needless to say, the structure that emerged in the early discussion depended on the parties, their knowledge, experience and conditioning. In a strict sense it was a political rather than a scientific structure. In such a situation, it was not possible to provide a cultural analysis of the parties' narrative and framing of the issues.

The exercise in discussing specific issues sometimes seemed to generate incompatible perceptions of what can and would be achievable in peace negotiations.

Table 15.1 List of outstanding issues organized by category

Geographic and demographic issues	Political issues	Behavioral issues
Access of Palestinians to available natural resources	Accountability and reasonability of Hamas in the gaza strip	Bad faith negotiations
Archeological issues	Agreement on one state solution	Compromise
Golan heights	Agreement on two state solution	Confidence building measures
How to address the Palestinian diaspora	AIPAC (American Israel Political Action Committee)	Corruption
How to re-settle Palestinian refugees	American politicians	Deception and manufacturing of history
Immigration	Citizenship rights of Palestinian community in Israel	Equal treatment of all parties
Palestinian access to the Mediterranean Sea	Colonialism	Ethnic cleansing
Palestinian problem of split land kass between Gaza and the West Bank	Condemnation of violence as a tool of negotiation	Harassment
Population	Control	Human rights
Problems for Israel in living in an ocean of arab countries	Denunciation of irrelevant united nations resolutions	Human shields
Right of Palestinians to return to their homes in Israel	European acceptance of responsibility for the holocaust and settlement of Israelis in Israel	Intermarriage
Rights of Palestinians to Israeli-controlled land	Funding of terrorism	Learning to forgive without forgetting
Status of israeli settlements	Historical legitimacy of ownership of land in the area	Love
Water	How to deal with charges of apartheid	Mutual recognition of rights of each party
Economic and business issues	International relationships	Non violence
Compensation for victims of terrorism	Islamic state	Psychological barriers
Compensation to palestinians for loss of land	Jewish refugee issues	Psychological damage
Dealing with property confiscation Issues	Mutual compensation	Racism
Economic choices	Problems associated with Hamas	Recognition of the holocaust
How to re-settle Palestinian refugees	Residency rights	Recognition of the nakba condition
Restitution	Role of the druze in negotiations	Religious fundamentalism

(continued)

Table 15.1 (continued)

Geographic and demographic issues	Political issues	Behavioral issues
Education Issues	Sovereignty	Representation of women in the negotiations
Education	Status of Israel	Respect
Incitement in the educational school system	Status of Jerusalem	Subjugation and humiliation
Indoctrination	Status of Palestinian authority	Suicide bombers
Industrial parks	Status of Ramallah	Trust
Lack of creativity and problem solving	Syrian accommodation for settlement of Palestinian refugees	*Military Issues*
Language training	*Social Issues*	Arms smuggling
Stolen culture	Basic human needs	Disarmament
Security issues	*Religious and ideological issues*	*House demolition*
Bombing of Israeli children	Armageddon	Invasion
Gilad shalit (release of prisoners)	Christian zionism (evangelists)	Missile building
Safe passage	Holy places	Nuclear responsibility
Safety and security	Jewish zionism	War crimes
Terrorism	Palestinian christians	*Legal issues*
The wall	Religious prophecy	International law
		Prisoners

For example, all the Israelis present were adamant that a one state solution is impossible to contemplate, while Palestinians all agreed that a solution that does not grant refugees their internationally recognized rights to return is also impossible to contemplate. But we do know that historically adamant positions have changed when circumstances change. For proper application of the AHP methodology, it is important to include in the structure all factors, including those that some participants feel are so crucial to their preconceived and predetermined positions, that any concession on those issues seems inconceivable.

In order to develop the necessary measurements for prioritization, we need to calculate the gains and losses for each concession from each of the parties. The panel developed a total of eight hierarchies involving benefits and costs and perceived benefits and costs: four hierarchies for the Israeli group and four hierarchies for the Palestinian group. The exercise in which the 106 issues were identified through the process of brainstorming served as a stimulus to the thinking of the participants to deal with the structuring process. Each of the eight hierarchies involves a goal, for example, Israel's Benefits from Palestinian Concessions, and a set of criteria that are a subset of the issues relevant to that goal. They are called criteria in terms of which all the possible concessions that were identified were evaluated by scoring them one at a time. The criteria that were developed for these eight models were chosen by each of the Israeli and Palestinian participants respectively. Because of the volume of issues, we found it necessary in developing

Table 15.2 Palestinian and Israeli concessions

Palestinian concessions

I. Compromise on sovereignty
  1. Accept two-state solution
  2. Accept a two state solution which includes a noncontiguous area-Gaza
  3. Acknowledge Israel's existence as a Jewish state
  4. Acknowledge Israel's existence as an independent state
  5. Make compromises on the status of Jerusalem

II. Compromise on right of return
  6. Agree to compromise on the demand of the right of return
  7. Lobby arab states to allow both Israelis and Palestinians to have the right to return to their land of origin
  8. Seek assistance for a legitimate settlement of refugees

III. Cooperate economically with Israel
  9. Drop opposition to trade and normal relations w/Israel
  10. Share all natural resources with Israel
  11. Work cooperatively and in active engagement with Israel

IV. Change attitude towards Israel
  1. Denounce iranian pursuit of nuclear arms and support Israel's efforts to remove the threat.
  2. Refrain from and work against any anti-Israel sentiments in Palestinian schools
  3. Denounce and rein-in violence

Israeli Concessions

I. Compromise on sovereignty
  1. Abandon the idea of a Jewish state
  2. Accept a two-state solution
  3. Comply with all applicable united nations resolutions
  4. Allow the sharing of all natural resources between Palestinians and Israelis
  5. Allow all parties to have equal access to and control of religious sites and holy places
  6. Share Jerusalem as both a religious and political center with all parties

II. Modify settlement activity
  7. Turnover settlement of Jewish settlers on land claimed by the Palestinians with or without compensation

III. Cooperate to improve human rights treatment
  8. Comply with human rights
  9. Implement Palestinian refugee rights
  10. Encourage equal opportunity for Palestinians to achieve equal economic prosperity
  11. Allow the right to have an education that is non-biased and equally shares historic backgrounds

IV. Remove access barriers
  12. Permit Palestinian freedom of movement
  13. Remove the wall and other barriers to Palestinian movement

the hierarchies to select as criteria a subset of the most crucial issues. The overall goal of each of the corresponding criteria in the four hierarchies involved the apparent equalization of the ratio of the gains to the losses by each side. Concessions by each party are listed in Table 15.2. We list the concessions which the participants identified as possible responses to the issues given in Table 15.1. We have classified these concessions into four categories for each side.

The forgoing concessions comprise the bottom levels of the hierarchies given in figures 1 and 2 in Appendix 1. The first level of these hierarchies are the criteria used to determine the contribution of the concessions to the benefits, costs, perceived benefits and perceived costs of both parties. The priorities of these criteria are given in Table 15.3.

The panels attempted to accomplish much in a very short period of time. To facilitate the process and reach some conclusions, we rated each concession under each criterion using the words and corresponding scale values in Table 15.4 as to how strongly it contributed to that criterion that represents the goal it serves. The result of this rating is given in Tables 15.5 and 15.6.

For example, in Table 15.5(a) Israeli's concessions were rated using only the highest priority criteria. Two criteria with negligible priorities, one in column four and one in column six had zero rating priorities for the concessions. These were ignored, ensuring that at least 70% of the priorities from the criteria were accounted for in the ratings model. Similarly, we did the same thing in the other tables. Tables 15.5(a, b, c, d) present the results for Israeli benefits from Palestinian concessions, Israeli perception of Palestinian costs for making these concessions to Israel, Israeli costs of their own concessions and finally, Israeli perception of Palestinian gains from Israeli concessions, respectively. Similarly, Tables 15.6 (a, b, c, d) present the results of the Palestinian ratings model.

Next, we weight the rating number for each criterion by the priority of that criterion and add for all the criteria to obtain the overall "Total" for each concession. Finally we divide by the "Total" priority of the concession that has the largest value; here it is "Acknowledge Israel as a Jewish State" to obtain the ideal priorities for the benefits of the concessions Israel gets. This is how we obtained the "Ideal" columns in the eight Tables15.5(a, b, c, d) and 15.6(a, b, c, d).

Thus, given two parties A and B, for every concession of party A there are associated with it costs and perceived gains of party B, as well as gains of party B and perceived costs of party A.

15.5 The Retributive Function

Given the entrenchment of both sides, a negotiator has an opportunity in an appropriate setting to call attention to the gap between the perceived benefits and costs of the concessions made by both sides and to help each party to reach a conclusion through the introduction of "bargaining chips." In the negotiation setting, if A and B are participants, then A considers a particular concession not only with respect to the incremental benefit (cost) to A but also the cost (benefit) to B in providing (receiving) the concession. The greater the perceived cost of each concession to B, the greater the value of that concession is to A.

Table 15.3 Priorities of criteria

Israeli criteria	Priorities: Israelis benefits from Palestinian concessions	Israelis perception of Palestinian costs	Israelis costs from their own concessions	Israelis perception of Palestinian gains from Israelis concessions
Benefits				
Control Jerusalem and holy places	0.245			
Refugee compensation and settlement	0.251			
Increasing security	0.193			
Permanent boarders	0			
Controlling and rationing of water	0.162			
Human rights	0.022			
Settlements in Palestinian territory	0.127			
Perceived Palestinian costs				
Lose argument of refugees		0.048		
Victim status		0.301		
Revolutionary cause as unifying factor		0.308		
Infrastructure		0.039		
Cost		0.268		
Accountability and responsibility		0.035		
Costs				
Economic			0.026	
Political			0.07	
Religious			0.002	
Psycholoical			0.119	
Security			0.274	
International Image			0.014	

(continued)

Table 15.3 (continued)

Israeli criteria	Priorities			
	Israelis benefits from Palestinian concessions	Israelis perception of Palestinian costs	Israelis costs from their own concessions	Israelis perception of Palestinian gains from Israelis concessions
Demographic			0.191	
Administration			0.021	
Civil disorder			0.185	
Social			0.095	
Unification of Jewish people			0.003	
Perceived Palestinian benefits				
International recognition				0.002
Member nations				0.017
Recognized borders				0.131
Peace				0.014
Independence				0.119
Economic trade				0.013
Law and order				0.085
Pride				0.619

Palestinian Criteria	Priorities			
	Palestinian benefits from Israelis concessions	Palestinian perception of Israelis costs	Palestinian costs from their own concessions	Palestinian perception of Israel gains from Palestinian concessions
Benefits				
Human rights	0.091			
Permanent borders	0.029			
Sovereign Palestinian state	0.13			

(continued)

Table 15.3 (continued)

Palestinian Criteria	Priorities			
	Palestinian benefits from Israelis concessions	Palestinian perception of Israelis costs	Palestinian costs from their own concessions	Palestinian perception of Israel gains from Palestinian concessions
Vacating of Israelis from settlement	0.167			
Freedom of movement	0.000			
Shared water and other resources	0.239			
Shared control of Jerusalem and holy places	0.025			
Resolution of refugee problem	0.288			
Security	0.017			
Two-way compensation	0.015			
Perceived Israeli Costs				
Ending of superiority		0.207		
Change of zionist narrative		0.037		
Property restitution and compensation		0.234		
Settlement evacuation		0.351		
Social restructuring		0.086		
Unity based on having a common identity		0.084		
Costs				
Political			0.131	
Economic			0.035	
Land/Sea control			0.279	
Psychological			0.034	
Religious			0.004	

(continued)

Table 15.3 (continued)

Palestinian Criteria	Priorities			
	Palestinian benefits from Israelis concessions	Palestinian perception of Israelis costs	Palestinian costs from their own concessions	Palestinian perception of Israel gains from Palestinian concessions
Social			0.032	
Quality of life			0.084	
International image			0.044	
Social harmony			0.019	
Not challenging Israel			0.017	
Property rights			0.318	
Perceived Israeli Benefits				
Peace of mind				0.167
Reduce fear of living				0.041
Retention of Israeli immigration				0.016
Leveraging resources				0.098
Acceptance of Israel with Islamic world				0.034
Acceptance of Israelis				0.037
Social harmony				0.015
Sharing of religious festival				0.021
Ending of apartheid				0.130
Enhanced economic development				0.172
Trade with region				0.270

Table 15.4 Ratings scale for concession evaluation

Excellent	1.0
Very high	0.9
High	0.8
Medium	0.7
Low	0.5
Very low	0.4
Negligible	0.3

Hence A’s gain from a given concession from B may be described as the product of A’s benefits and B’s costs (as perceived by A). We have the following ratios for the two parties A and B: (according to *A*’s perceptions) *A*’s ratio:

$$\frac{\text{Gain to A from B's Concession}}{\text{A's Perception of B's Gain from A's Concession}} = \frac{\sum \text{A's benefits} \times \text{B's costs from B's Concession}}{\sum \text{B's perceived benefits} \times \text{A's costs from A's Concession}}$$

where $\sum$ is the sum over all the benefits obtained by A in the numerator and by B in the denominator. Hence, given A’s ratio, A’s gain is a product of both the utility benefit received and the cost to B in providing that benefit as described in the numerator of the equation. The total gain to A is diminished by the product of the cost to A in concessions given to B and the perception of the benefit received by B for A’s concessions in the denominator. A’s benefits and costs are readily measured by A; however, the costs and gains to B are not readily available to A and are therefore estimated as perceived by A. A expects to have a gain ratio greater than one which suggests that the gains to A are greater than the perceived benefits to B. Likewise, B expects to have a gain ratio greater than one. For equality in ‘trade’ to be achieved, the two parties should be nearly equal in value, which suggests that the two gain as much as the perceived benefits to and costs of concessions to the other. B’s utility is given by the function: (according to B’s perceptions) B’s ratio:

$$\frac{\text{Gain to B from A's Concession}}{\text{B's Perception of A's Gain from B's Concession}} = \frac{\sum \text{B's benefits} \times A\text{'s costs from A's Concession}}{\sum \text{A's perceived benefits} \times \text{B's costs from B's Concession}}$$

The measure of equality between the parties in the trade of concessions may be calculated as the ratio of the two ratios:

A’s Ratio/B’s Ratio = Retributive Gain(Loss) to A.

Where the retributive gain is the amount that A benefits from making B ‘pay’ while a loss is accounted for by the amount that A ‘lost’ in the negotiation process. Under no circumstance would we expect A to agree to concessions when there is a perceived loss when A has dominance over B. In the case where A has dominance over B, the best that B can do is to minimize the disparity in gains.

Table 15.5 Israeli's concession ratings relative to criteria.

(a) Israeli's Benefits from Palestinians' Concessions

Priorities Criteria Concessions	0.245 Control Jerusalem and holy place	0.251 Refugee Compermation and settlement	0.193 Increasing security	0.000 Permanent borders	0.162 Controlling and resoning of water	0.022 Human rights	0.127 Settlement in Puleslins territory	Total	Ideals
Accept two-state solution	Very low	Excellent	Excellent	–	Negligible	–	Medium	0.680	0.736
Acceptance of non-contiguous state	Negligible	Excellent	Excellent	–	Negligible	–	Negligible	0.605	0.655
Acknowledge Israel's existence as a Jewish State	Excellent	Excellent	Excellent	–	Very high	–	Medium	0.924	1.000
Acknowledge Israel's existence as an independent state	Medium	High	High	–	Very high	–	Medium	0.762	0.824
Agree to compromise to demand of right of no return	High	Excellent	Excellent	–	Excellent	–	Very high	0.917	0.992
declare against Iranian nuclear development	–	–	–	–	–	–	–	0.000	0.000
Drop opposition to trade and normal relations w/Israel	Negligible	Very low	Very low	–	Negligible	–	High	0.402	0.435
Incitement of anti-Israeli sentiment in school	Excellent	Excellent	Excellent	–	Negligible	–	Very high	0.853	0.923
Lobby arab states to allow Israelis Right to return	–	–	–	–	–	–	–	0.000	0.000
Make compromise on the status of Jerusalem	Excellent	Low	Excellent	–	–	–	Medium	0.653	0.707
Denounce and reign in violence	Excellent	Very low	Excellent	–	High	–	Excellent	0.795	0.860
Seek assistance for a legitimate settlement of refugees	Negligible	Excellent	Excellent	–	–	–	Negligible	0.556	0.602

(continued)

Table 15.5 (continued)

(a) Israeli's Benefits from Palestinians' Concessions

Priorities Criteria Concessions	0.245 Control Jerusalem and holy place	0.251 Refugee Compermation and settlement	0.193 Increasing security	0.000 Permanent borders	0.162 Controlling and resoning of water	0.022 Human rights	0.127 Settlement in Puleslins territory	Total	Ideals
Sharing of natural resources	Negligible	Very low	Medium	–	Negligible	–	High	0.459	0.497
Work cooperatively w/Israel	Negligible	Very low	Excellent	–	Very high	–	Negligible	0.677	0.732

(b) Israeli's perceptions of Palestinian's costs

Priorities Criteria Concessions	0.048 Lose argument of refugees	0.301 Viction status	0.308 Revoluliorury cause as undifying factor	0.039 Infrastructure	0.268 Cost	0.035 Accountability and responsibility	Total	Ideals
Accept two-state solution	–	Negligible	Excellent	–	Excellent	–	0.667	0.967
Acceptance of non-contiguous State	–	Excellent	Excellent	–	Negligible	–	0.690	1.000
Acknowledge Israel's existence as a Jewish state	–	Negligible	High	–	Negligible	–	0.418	0.605
Acknowledge Israel's existence as an independent state	–	Negligible	Excellent	–	Negligible	–	0.479	0.695
Agree to compromise to demand of Right of no return	–	Excellent	Excellent	–	Negligible	–	0.690	1.000

(continued)

Table 15.5 (continued)

(b) Israeli's perceptions of Palestinian's costs

Priorities Criteria Concessions	0.048 Lose argument of refugees	0.301 Viction status	0.308 Revoluliorury cause as undifying factor	0.039 Infrastructure	0.268 Cost	0.035 Accountability and responsibility	Total	Ideals
Declare against Iranian nuclear development	–	–	–	–	–	–	0.000	0.000
Drop opposition to trade and normal relations w/Israel	–	High	High	–	Negligible	–	0.568	0.823
Incitement of anti-Israeli sentiment in school	–	Excellent	Excellent	–	Negligible	–	0.690	1.000
Lobby arab states to allow Israelis right to return	–	–	–	–	–	–	0.000	0.000
Make compromise on the status of Jerusalem	–	Negligible	High	–	Negligible	–	0.418	0.605
Denounce & reign in violence	–	Excellent	High	–	Negligible	–	0.628	0.911
Seek assistance for a legitimate settlement of refugees	–	Low	Excellent	–	Negligible	–	0.539	0.782
Sharing of natural resources	–	Medium	High	–	Medium	–	0.645	0.935

(continued)

Table 15.5 (continued)

(b) Israeli's perceptions of Palestinian's costs

Priorities Criteria Concessions	0.048 Lose argument of refugees	0.301 Viction status	0.308 Revoluliorury cause as undifying factor	0.039 Infrastructure	0.268 Cost	0.035 Accountability and responsibility	Total	Ideals
Work cooperatively w/Israel	–	Negligible	High	–	Negligible	–	0.418	0.605

(c) Israeli's costs from their own concessions

Priorities Criteria Concessions	0.026 Economic	0.070 Political	0.002 Religious	0.119 Psychological	0.274 Security	0.014 International inuge	0.191 Demographic	0.021 Administration	0.185 Civil disorder	0.095 Social	0.003 Unification of Jewish people	Total	Ideals
Abandon the idea of Jewish state	–	–	–	Excellent	Excellent	–	Excellent	–	Excellent	–	–	0.769	1.000
Accept two-state solution	–	–	–	Medium	Negligible	–	Negligible	–	High	–	–	0.371	0.482
comply with UN resolutions	–	–	–	Excellent	Excellent	–	Excellent	–	Excellent	–	–	0.769	1.000
Human rights	–	–	–	Negligible	Negligible	–	Negligible	–	Negligible	–	–	0.231	0.300
Implementation of refugee rights	–	–	–	Excellent	Excellent	–	Excellent	–	Excellent	–	–	0.769	1.000
Palestinian freedom of movement	–	–	–	Excellent	Excellent	–	Excellent	–	Excellent	–	–	0.769	1.000
Removal of wall and other barriers	–	–	–	Excellent	Excellent	–	Negligible	–	Excellent	–	–	0.635	0.826
Right to economic opportunity	–	–	–	Negligible	Negligible	–	Negligible	–	Negligible	–	–	0.231	0.300
Right to education	–	–	–	Negligible	Negligible	–	Negligible	–	Negligible	–	–	0.231	0.300
Shared administration of resources	–	–	–	Medium	Low	–	Negligible	–	Medium	–	–	0.407	0.529

(continued)

Table 15.5 (continued)

(c) Israeli's costs from their own concessions

Priorities Criteria Concessions	0.026 Economic	0.070 Political	0.002 Religious	0.119 Psychological	0.274 Security	0.014 International inuge	0.191 Demographic	0.021 Administration	0.185 Civil disorder	0.095 Social	0.003 Unification of Jewish people	Total	Ideals
Shared control of holy places	–	–	–	Negligible	Negligible	–	Negligible	–	Excellent	–	–	0.360	0.468
Shared Jerusalem	–	–	–	Excellent	High	–	Negligible	–	Excellent	–	–	0.580	0.755
Turnover settlement w/wo compensation	–	–	–	Excellent	Negligible	–	Negligible	–	Excellent	–	–	0.444	0.577

(d) Israeli's perceptions of Palestinians' gains

Priorities Criteria Concessions	0.002 International recognition	0.017 Member Nations	0.131 Recognized borders	0.014 Peace	0.119 Independence	0.013 Economic trade	0.085 Law and order	0.619 Pride	Total	Ideals
Abandon the idea of Jewish state	–	–	Excellent	–	Excellent	–	–	Excellent	0.869	1.000
Accept two-State solution	–	–	Negligible	–	Excellent	–	–	Very High	0.715	0.823
Comply with UN resolutions	–	–	Excellent	–	Excellent	–	–	Excellent	0.869	1.000
Human rights	–	–	Negligible	–	Negligible	–	–	Negligible	0.261	0.300
Implementation of refugee rights	–	–	Negligible	–	Excellent	–	–	Excellent	0.777	0.894
Palestinian freedom of movement	–	–	Excellent	–	Excellent	–	–	Excellent	0.869	1.000
Removal of wall and other barriers	–	–	Negligible	–	High	–	–	Excellent	0.753	0.867
Right to economic opportunity	–	–	Negligible	–	Negligible	–	–	Negligible	0.261	0.300
Right to education	–	–	Negligible	–	Negligible	–	–	Negligible	0.261	0.300

(continued)

Table 15.5 (continued)

(d) Israeli's perceptions of Palestinians' gains

Priorities Criteria Concessions	0.002 International recognition	0.017 Member Nations	0.131 Recognized borders	0.014 Peace	0.119 Independence	0.013 Economic trade	0.085 Law and order	0.619 Pride	Total	Ideals
Shared administration of resources	–	–	Negligible	–	High	–	–	Medium	0.568	0.653
Shared control of holy places	–	–	Negligible	–	High	–	–	Excellent	0.753	0.867
Shared Jerusalem	–	–	Excellent	–	Excellent	–	–	Excellent	0.869	1.000
Turnover settlement w/wo compensation	–	–	Excellent	–	Excellent	–	–	Excellent	0.869	1.000

Table 15.6 Palestinian concession ratings relative to criteria.

(a) Palestinians' benefits from Israeli's concessions

Priorities Criteria Concessions	0.091 Human rights	0.029 Permited borders	0.130 Sovergin Palestinian state	0.167 Vacancing of Israel from settlement	0.000 Freedom of movement	0.239 Shared water and other resources	0.025 Shared control of Jerusalem	0.288 Resolution of refugee problem	0.017 Security	0.015 Two-way compersation	Total	Ideals
Abandon the idea of Jewish state	Excellent	–	Medium	Medium	–	Low	–	Excellent	–	–	0.705	0.80
Accept two-state solution	Medium	–	Very high	Excellent	–	Very high	–	Very low	–	–	0.677	0.76
Comply with UN resolutions	Very high	–	Excellent	Excellent	–	Very high	–	Excellent	–	–	0.881	1.00
Human rights	Excellent	–	High	Very High	–	High	–	Excellent	–	–	0.823	0.93
Implementation of refugee rights	Excellent	–	Excellent	Medium	–	High	–	Excellent	–	–	0.816	0.92
Palestinian freedom of movement	Very high	–	Excellent	Excellent	–	Medium	–	Low	–	–	0.689	0.78
Removal of wall and other barriers	Excellent	–	Excellent	High	–	Very high	–	Medium	–	–	0.770	0.87
Right to economic opportunity	Very high	–	Excellent	High	–	Very high	–	Low	–	–	0.703	0.79
Right to education	Very high	–	Excellent	Medium	–	Medium	–	Low	–	–	0.639	0.72
Shared administration of resources	Very high	–	Very high	Medium	–	Excellent	–	Low	–	–	0.698	0.79
Shared control of Holy places	Medium	–	High	Very high	–	Medium	–	Very low	–	–	0.600	0.68
Shared Jerusalem	Medium	–	High	Very High	–	Medium	–	Medium	–	–	0.686	0.77
Turnover settlement w/wo compensation	High	–	Very high	Excellent	–	High	–	Medium	–	–	0.748	0.85

(b) Palestinians' perceptions of Israelis' costs

Priorities Criteria Concessions	0.207 Ending of superiority	0.037 Change of Ziorist narrative	0.234 Property restination	0.351 Settlement evicaution	0.086 Social restructuring	0.084 Unity based on shared identity	Total	Ideals
Abandon the Idea of Jewish state	Excellent	–	Excellent	Medium	–	–	0.688	0.951

(continued)

Table 15.6 (continued)

(b) Palestinians' perceptions of Israelis' costs

Priorities Criteria Concessions	0.207 Ending of superiority	0.037 Change of Ziorist narrative	0.234 Property restination	0.351 Settlement evicaution	0.086 Social restructuring	0.084 Unity based on shared identity	Total	Ideals
Accept two-state Solution	High	–	Medium	High	–	–	0.611	0.845
Comply with UN resolutions	Excellent	–	Medium	Excellent	–	–	0.723	1.000
Human rights	Excellent	–	Very High	Medium	–	–	0.664	0.919
Implementation of refugee rights	Very High	–	Very High	Very High	–	–	0.714	0.988
Palestinian freedom of movement	Very High	–	Low	Medium	–	–	0.550	0.761
Removal of wall and other barriers	High	–	High	Medium	–	–	0.599	0.829
Right to economic opportunity	High	–	Medium	Medium	–	–	0.576	0.797
Right to education	Very Low	–	Low	Low	–	–	0.376	0.520
Shared administration of resources	Very High	–	High	High	–	–	0.655	0.907
Shared control of Holy places	Medium	–	Medium	Very High	–	–	0.625	0.865
Shared Jerusalem	Medium	–	Medium	Very High	–	–	0.625	0.865
Turnover settlement w/ wo compensation	Very High	–	Very High	Very High	–	–	0.714	0.988

Table 15.6 (continued)

(c) Palestinians' costs from their own concessions

Priorities Criteria Concessions	0.131 Political	0.035 Economic	0.279 Land/ sea control	0.034 Pscycological	0.004 Religious	0.032 Social	0.084 Quality of life	0.044 International image	0.019 Social harmony	0.017 Not challenging Israel	0.318 Property rights
PoliticalAccept two-state solution	Very High	–	Very High	–	–	–	High	–	–	–	Very High
Acceptance of non-contiguous state	Excellent	–	Excellent	–	–	–	Excellent	–	–	–	Very High
Acknowledge Israel's existence as a Jewish state	High	–	High	–	–	–	Medium	–	–	–	High
Acknowledge Israel's existence as an independent state	Excellent	–	Very High	–	–	–	Very High	–	–	–	Excellent
Agree to Compromise to demand of right of no return	Excellent	–	Very high	–	–	–	Excellent	–	–	–	Excellent
Declare against Iranian nuclear development	Medium	–	Negligible	–	–	–	Very low	–	–	–	Negligible
Drop opposition to trade & normal relations w/Israel	Very high	–	Medium	–	–	–	Low	–	–	–	Medium
Incitement of anti-Israeli sentiment in school	Very low	–	Negligible	–	–	–	Very low	–	–	–	Negligible
Lobby Arab states to Allow Israelis right to return	Very low	–	Very low	–	–	–	Medium	–	–	–	Low
Make compromise on the status of Jerusalem	Very high	–	Medium	–	–	–	Very high	–	–	–	Excellent
Denounce & reign in violence	Excellent	–	Very Low	–	–	–	Low	–	–	–	Negligible
Seek assistance for a legitimate settlement of refugees	Medium	–	Medium	–	–	–	Medium	–	–	–	Excellent
Sharing of natural resources	Medium	–	Very High	–	–	–	Very high	–	–	–	High
Work cooperatively w/Israel	High	–	Low	–	–	–	Medium	–	–	–	Medium

Table 15.6 (continued)

(c) Palestinians' costs from their own concessions

Priorities Criteria Concessions	0.000 Public standing	0.000 Access to resources	0.000 Access to family	0.000 International standing	0.000 Identity	0.000 Moral	0.000 Division	Total	Ideals
PoliticalAccept two-state solution	–	–	–	–	–	–	–	0.723	0.921
Acceptance of non-contiguous state	–	–	–	–	–	–	–	0.781	0.995
Acknowledge Israel's existence as a Jewish state	–	–	–	–	–	–	–	0.642	0.818
Acknowledge Israel's existence as an independent state	–	–	–	–	–	–	–	0.777	0.989
Agree to Compromise to demand of right of no return	–	–	–	–	–	–	–	0.785	1
Declare against Iranian nuclear development	–	–	–	–	–	–	–	0.305	0.388
Drop opposition to trade & normal relations w/Israel	–	–	–	–	–	–	–	0.578	0.737
Incitement of anti-Israeli sentiment in school	–	–	–	–	–	–	–	0.265	0.338
Lobby Arab states to Allow Israelis right to return	–	–	–	–	–	–	–	0.382	0.487
Make compromise on the status of Jerusalem	–	–	–	–	–	–	–	0.708	0.901
Denounce & reign in violence	–	–	–	–	–	–	–	0.381	0.485
Seek assistance for a legitimate settlement of refugees	–	–	–	–	–	–	–	0.664	0.847
Sharing of natural resources	–	–	–	–	–	–	–	0.673	0.858
Work cooperatively w/Israel	–	–	–	–	–	–	–	0.526	0.671

Table 15.6 (continued)

(d) Palestinians' perceptions of Israelis' gains

Priorities Criteria Concessions	0.167 Piece of mind	0.041 Reduced of living	0.016 Resolution of Israel imagination	0.098 Lawringring resources	0.034 Acceptance of Islamic world	0.037 Acceptance of Israeli	0.015 Social harmony	0.021 Sharing of religious festivals	0.130 Ending of apartheid	0.172 Enhanced economic development	0.270 Trade with region	Total	Ideals
Accept two-state solution	Very High	–	–	–	–	–	–	–	Very Low	Medium	Medium	0.511	0.807
Acceptance of Non-Contiguous State	Very High	–	–	–	–	–	–	–	Very Low	Low	Negligible	0.369	0.582
Acknowledge Israel's existence as a Jewish state	Very High	–	–	–	–	–	–	–	Medium	Medium	High	0.577	0.911
Acknowledge Israel's existence as an independent state	Excellent	–	–	–	–	–	–	–	Negligible	Very Low	Negligible	0.356	0.561
Agree to compromise to demand of right of no return	Excellent	–	–	–	–	–	–	–	Low	Negligible	Very Low	0.391	0.618
Declare against Iranian nuclear development	Very High	–	–	–	–	–	–	–	Negligible	Negligible	Very Low	0.349	0.550
Drop opposition to trade and normal relations w/Israel	Medium	–	–	–	–	–	–	–	Very High	Medium	Very High	0.597	0.942
Incitement of Anti-Israeli sentiment in school	Very Low	–	–	–	–	–	–	–	High	Negligible	Negligible	0.303	0.479
Lobby Arab states to allow Israelis right to return	Negligible	–	–	–	–	–	–	–	Low	High	Very High	0.495	0.782
Make Compromise on the status of Jerusalem	High	–	–	–	–	–	–	–	Medium	Very High	High	0.595	0.939

(continued)

Table 15.6 (continued)

(d) Palestinians' perceptions of Israelis' gains

Priorities CriteriaConcessions	0.167 Piece of mind	0.041 Reduced of living	0.016 Resolution of Israel imagination	0.098 Lawringring resources	0.034 Acceptance of Islamic world	0.037 Acceptance of Israeli	0.015 Social harmony	0.021 Sharing of religious festivals	0.130 Ending of apartheid	0.172 Enhanced economic development	0.270 Trade with region	Total	Ideals
Denounce & reign in violence	Very High	–	–	–	–	–	–	–	Excellent	High	High	0.634	1.000
Seek assistance for a legitimate settlement of refugees	Very High	–	–	–	–	–	–	–	Very Low	Low	Medium	0.477	0.753
Sharing of natural resources	Very High	–	–	–	–	–	–	–	High	Medium	Medium	0.563	0.889
Work Cooperatively w/ Israel	High	–	–	–	–	–	–	–	High	High	High	0.591	0.933

Table 15.7 Israeli's ratios

Israeli's ratios	Accept two-state solution	Acceptance of non-contiguous state	Acknowledge Israel's existence as a Jewish state	Acknowledge Israel's existence as an independent state	Agree to compromise to demand of right of no return	Declare against Iranian nuclear development	Drop opposition to trade & normal relations w/Israel	Incitement of Anti-Israeli sentiment in school	Lobby Arab states to allow Israelis right to return	Make compromise on the status of Jerusalem	Denounce & reign in violence	Seek assistance for a legitimate settlement of refugees	Sharing of natural resources	Work cooperatively w/Israel
Abandon the idea of Jewish state	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Accept two-state solution	1.588	1.451	1.550	1.113	2.214	0.000	0.000	2.060	0.000	0.000	1.749	1.109	1.038	0.000
Comply with UN resolutions	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Human rights	7.906	7.273	7.717	5.542	11.022	0.000	3.975	10.251	0.000	4.934	8.706	5.522	5.167	4.923
Implementation of refugee rights	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Palestinian freedom of movement	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Removal of wall and other barriers	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Right to economic opportunity	7.906	7.273	7.717	5.542	11.022	0.000	3.975	10.251	0.000	4.934	8.706	5.522	5.167	4.923
Right to education	7.906	7.273	7.717	5.542	11.022	0.000	3.975	10.251	0.000	4.934	8.706	5.522	5.167	4.923
Shared administration of resources	1.928	1.774	1.882	1.352	2.689	0.000	0.000	2.501	0.000	1.204	2.124	1.347	1.260	1.201
Shared control of holy places	1.753	1.613	1.711	1.229	2.444	0.000	0.000	2.273	0.000	1.094	1.931	1.225	1.146	1.092
Shared Jerusalem	0.000	0.000	0.000	0.000	1.314	0.000	0.000	1.222	0.000	0.000	1.038	0.000	1.038	0.000
Turnover settlement w/ wo compensation	1.234	1.135	1.204	0.000	1.720	0.000	0.000	1.599	0.000	0.000	1.358	0.000	0.000	0.000

Table 15.8 Palestinian's ratios

Palestinian's Ratios	Accept two-state solution	Acceptance of non-contiguous state	Acknowledge Israel's existence as a Jewish state	Acknowledge Israel's existence as an independent state	Agree to compromise to demand of right of No return	Declare against Iranian nuclear development	Drop opposition to trade and normal relations w/Israel	Incitement of Anti-Israeli sentiment in school	Lobby Arab states to allow Israelis right to return	Make compromise on the status of Jerusalem	Denounce and reign in violence	Seek assistance for a legitimate settlement of refugees	Sharing of natural resources	Work cooperatively w/Israel
Abandon the idea of Jewish state	1.060	1.300	1.420	1.057	1.235	3.691	1.175	4.866	1.864	0.000	1.588	1.217	1.054	1.196
Accept two-state solution	0.000	1.072	1.171	0.000	1.019	3.045	0.000	4.014	1.538	0.000	1.310	1.004	0.000	0.000
Comply with UN resolutions	1.345	1.350	1.802	1.342	1.567	4.686	1.491	6.177	2.366	1.182	2.016	1.545	1.338	1.518
Human rights	1.156	1.418	1.548	1.153	1.347	4.026	1.281	5.306	2.033	1.015	1.732	1.327	1.149	1.304
Implementation of refugee rights	1.231	1.510	1.649	1.228	1.434	4.287	1.364	5.661	2.166	1.081	1.844	1.413	1.224	1.389
Palestinian freedom of movement	0.000	1.067	1.166	0.000	1.013	3.029	0.000	3.993	1.530	0.000	1.303	0.000	0.000	0.000
Removal of wall and other barriers	0.000	1.197	1.307	0.000	1.137	3.398	1.081	4.479	1.716	0.000	1.462	1.120	0.000	1.101
Right to economic opportunity	0.000	1.093	1.194	0.000	1.038	3.105	0.000	4.092	1.568	0.000	1.336	1.023	0.000	1.006
Right to education	0.000	0.000	0.000	0.000	0.000	2.136	0.000	2.815	1.078	0.000	0.000	0.000	0.000	0.000
Shared administration of resources	1.006	1.234	1.348	1.004	1.172	3.504	1.115	4.619	1.769	0.000	1.508	1.155	1.000	1.135
Shared control of holy places	0.000	0.000	1.022	0.000	0.000	2.667	0.000	3.502	1.342	0.000	1.143	0.000	0.000	0.000
Shared Jerusalem	0.000	1.070	1.169	0.000	1.017	3.040	0.000	4.006	1.535	0.000	1.308	1.002	0.000	0.000
Turnover settlement w/ wo compensation	1.129	1.385	1.513	1.126	1315	3.933	1.251	5.184	1.986	0.000	1.692	1.296	1.123	1.274

Table 15.9 Matching concessions with corresponding gain/loss ratios

	Israeli's concessions	Gain/Loss ratio		Palestinian's concessions	Gain/Loss ratio
4	Shared administration of resources	1.03	9	Drop opposition to trade and normal relations w/Israel	1.03
3	Comply with UN resolutions	7.27	2	Acceptance of non-contiguous State	7.27
10	Right to economic development		13	Incitement of Anti-Israeli sentiment in school	
5	Shared control of holy places	2.77	4	Acknowledge Israel's existence as an independent state	2.77
7	Turnover settlement w/without compensation		14	Denounce and reign in violence	
2	Accept two-state solution	1.08	5	Make compromise on the status of Jerusalem	1.08
6	Shared Jerusalem		11	Work cooperatively w/Israel	
9	Implementation of refugee rights	5.17	12	Declare against Iranian nuclear development	5.17
12	Palestinian freedom of movement		7	Lobby Arab states to allow Israelis to have the right to return	
11	Right to education		10	Sharing of natural resources	
8	Human rights	7.90	1	Accept two-state solution	1.16
13	Removal of wall and other barriers	0.00			

The ratios for the Israelis and the Palestinians based on the benefits and costs, and perceived benefits and costs are given in Tables 15.7 and 15.8. When a ratio was less than one the ratio was made equal to zero to signify that a tradeoff was not acceptable. These ratios are used to make tradeoffs among concessions according to two criteria: (1) both parties should get as much as possible from the concession(s), and (2) the gains from the concession(s) for both parties should be as close as possible. The first criterion is the objective function of a MaxMin problem, while the second criterion is imposed as a constraint (see Appendix 2).

15.6 Discussion: The Gain to Loss Ratios of Concessions Made by Both Sides Need to be Close to One Another

One of the key takeaways that all participants in the exercise appreciated was that they learned more about the other party. One of the primary challenges to the approach turned out to be the same item that created a greater depth in understanding: a lack of common definitions. A lack of common definitions challenged the participants to actively engage in deeper understanding of each other. For future exercises of this sort though, we suggest that one of the first steps to pursue is to define terms and language. For instance, one of the concessions that is offered is to direct more effort to "Human Rights". How the parties define 'human rights', however, differs greatly. Even though philosophically there should be an easily determined common definition for "human rights", the reality is that the parties took different positions on this issue.

The judgment and prioritization process for the concessions was implemented for each party without knowledge of the other party.

The object is to make the ratios of the two parties close. Each party can by itself estimate the gain to loss ratio of its opponent and determine if his gain to loss ratio is much greater than the other party's gain to loss ratio. That also makes the negotiations more difficult. The original model sought a solution that matched the best one-to-one concession. However, given that the best solution was a standoff, we found that one had to consider trading off bundles of concessions. The role of the mediator is extremely important in this setting. There are two ways that the mediator can help to alter the outcome of ratios. Recall that both the numerator and the denominator of the ratio includes perceptions of the other; in the numerator is what one party perceives the cost of concessions are to the adversary; whereas the denominator includes what one party perceives the other party's benefits. It is interesting to note that in a retributive conflict one party perceives the costs to the adversary as a benefit to itself and conversely the gain to the adversary as a loss to itself. The mediator has a real opportunity to bridge gaps, given the measured difference between the two parties and their varying perceptions, interpretations and respect for "international" law.

Our results underline the differences between the Israelis and the Palestinians. In particular, the findings highlight the value of the Israelis' concessions as measured by the Palestinians when compared with the Palestinians' concessions as measured by the Israelis through the large differences in ratios. Given this disparity, there is great opportunity by one party to take a leadership role in the resolution process. Moreover, there is an even greater opportunity for a mediator to help bridge the gap in the gain-to-loss ratios. By educating both parties on the true costs and benefits to the adversary, the perceptions are brought more in line with reality and the score differences minimized. It is possible that external influences or pressures might be necessary to rationalize the difference in the gain-to-loss ratios in order to recognize the discrepancies.

15.7 Equalizing Concession Trade-Offs

Mistrust and the inclination to act retributively prevent people from making all their concessions at once. To determine the fairest and maximum gain to both parties from concessions being traded off, we computed gain–loss ratios for each pair of concessions, one for each party. These gain–loss ratios represent the gain to one party from the concession made by the other party divided by that party's loss from the concession it made. The gain to one party's concession is obtained as the benefits accrued from the other party's concession multiplied by the perceived costs to the party making the concession. The loss to one party's concession is obtained as the costs of the concession it made multiplied by the perceived benefits to the other party. To make the tradeoffs we considered only pairs of concessions with gain–loss ratios for both parties greater than one. This means that either side would be reluctant to trade-off a concession in return for another from which its gain is less than its loss.

The tradeoff process started by attempting to trade-off single concessions with two objectives in mind: closeness of the gain-to-loss ratios and maximization of the ratio. If there were no single concessions that could be traded that satisfied both criteria to ensure fairness, then groups of concessions were considered for tradeoff to satisfy the same requirements. As a result of this process we obtained Table 15.9.

The concessions in Table 15.9, numbered as in Table 15.2, are traded off while maximizing the gain to loss ratio for each side and minimizing the difference between these ratios to within 1% from each other except for the very last concessions which can only be traded if the 1% constraint is relaxed. All the concessions have been traded off except for the ones related to the resettlement of refugees (concession 1 for the Israelis from Table 15.2) and the acceptance of Israel by the Palestinians as a secure, independent and democratic Jewish state (concessions 3, 6 and 8 for the Palestinians from Table 15.2). These concessions will need to be addressed as the process is continued.

The outcome shows that with the exception of the two concessions mentioned above, all the other concessions can be traded off either singly or in groups against other concessions without violating the constrains previously established, namely that the gain-loss ratios be not too large and as close to one another as possible. One might question the advantage of trading off all of the concession identified to date without addressing the two major issues mentioned above. Prior negotiations have been hampered by the chaos or confusion caused by trying to address all of the issues at the same time. What this process permits is eliminating either temporarily or permanently any discussion that would impede attention to the two major matters that seem the most acrimonious and potentially irreconcilable. Another reason to take care of the tradable issues first is to give the parties experience in interacting successfully with one another, thus engendering a spirit of trust which could be very helpful when the final few but crucially important issues are considered.

Note, for example that the Israeli concession, "Shared Administration of Resources" trades off against the Palestinian concession "Drop Opposition to Trade and Normal Relations with Israel" with a resulting gain–loss ratio for both sides of about 1.03. Similarly, the remaining concessions are traded off against those of the other side in groups of two and three. The final two Israeli concessions in Table 15.3 do not tradeoff against the last Palestinian concession.

It should be noted that the solution to the refugee problem includes removing the three concessions 3, 6 and 8, all of which relate to this issue. However, only the single Israeli concession 1 needs to be removed from the present deliberations.

Tradeoffs of these concessions would require focusing the AHP process only on these matters with the possible participation of influential outside parties

15.8 Problems of Implementation: Some Skeptical Observations

"The problems we have today cannot be solved by thinking the way we thought when we created them," said Albert Einstein.

It is possible that either side would be reluctant to accept the outcome of the tradeoff of bundles of concessions. Optimally these bundles of concessions when compared both maximize the gain loss ratio for each side and also seek equality of this ratio for both sides. However, even though the solution may be optimal, there may still be retributive concern that the other side may be getting more or that they may have forgotten some important concessions they want or they do not trust their judgments or cannot completely divest the emotions generated over a long period of time.

It may be that the Israelis and Palestinians have lived with this conflict for so long that they do not think an acceptable resolution is possible. People who have suffered pain for a long time have expectations about what would make them feel better and a rational solution would not necessarily satisfy those feelings. We all have a tendency to believe in the mystical, that the hand of God must be allowed to do its work and miracles do happen. But does that hand act without action by the parties?

Given the length of time that this controversy has endured, is there a possibility that the parties at risk would reject an outcome that has embedded long standing biases and emotions into a solution that considers all conceivable factors and which produces a recommended outcome which gives both parties an approximately equivalent set of benefits and costs. The answer may be yes. So of what value has this process been? Should such reluctance be observed, this will in no way invalidate the efficacy of this approach.

The approach opens up an avenue of new thinking. Even if people reject the first effort, it may only need to be modified a bit to make it acceptable or in any case people may reject the unknown but they live with it long enough for it to become an accepted and natural way of thinking. People may be less likely to reject a second or a third revised effort.

While it would be appealing for the parties to implement the recommended solution, it may not be possible do so without the influence or even coercion of outside parties such as the United Nations, the United States, the European Union and Russia. Some of the concessions cannot be implemented without supervision.

15.9 Conclusions

Our objective has been to see if the Analytic Hierarchy Process (AHP), a new approach to group decision-making, could be used productively to move forward the 60 year old debate about solving the perplexing Middle East problem. It was not our intention to use the process to discover a specific solution to the Israeli–Palestinian conflict. The AHP provided us with a new way to pursue the dialogue in a context which uses a quantitatively-oriented approach to attach numerical priorities to the issues in what has been an emotionally charged conflict. Our purpose has been to introduce a process which, were it to be used by the actual negotiators, might offer some new ways of moving forward on the heretofore intractable positions adopted by the parties.

One may ask how can a process like this add meaning to the plethora of proposed solutions that have either fallen on deaf ears over 60 years or been destroyed because of the impossibility of implementation? It is important to state the idea that the AHP is a supplement and not a replacement for face to face negotiations. Whenever the process has broken down in the past, there has been no next step to take. A number of entities have stepped forward to try to jump start the stalled negotiation. The United States has been the foremost player in this remediation effort. They have tried to determine what would be a fair outcome but to date there has been no real way to measure which initiative would constitute a fair and equitable package, because the issues are so varied, complex, interrelated and affected by extreme emotions. AHP provides an alternative approach by helping the parties to either think outside the box by themselves or engage in exercises which force this creative behavior. In its simplest terms AHP would require the actual negotiator to make judgments in a novel way. The outcome of their judgments could provide an outsider like the United States with some confidence that an AHP type solution would yield an outcome that is as fair to each side as is possible with current technology. A third party could then encourage the parties to consider such a solution with increased confidence that the approach allows, for example, the United States to act in a neutral position with some confidence that as fair a solution as possible is being promoted.

It is important to note that the participants in our meetings were knowledgeable, informed, thoughtful Israelis and Palestinians, who might be able to recommend to actual negotiators ideas and ways to solve this long-simmering problem. They were engaged in a simulation—a process to find out if these participants had been, indeed, the actual negotiators, would they have been able to stay with the negotiations and to reach some productive outcome. Whether these participants were representative of their respective constituencies is irrelevant, since the results of their deliberations were never expected to produce a solution to the problem, but merely to test an approach. The outcomes of the deliberations suggested a number of important benefits if the approach were actually used by real-life negotiators.

We have attempted to find out how the process would work: would it provide a modicum of an objective basis to trade off the concessions and help to drain the emotions, so far as was possible, out of discussions of contentious issues? It was done by rating the issues to prioritize them and then rate the concessions with respect to each issue. We established priorities by assigning quantitative values, which would encourage negotiators to deal with the importance of one issue as compared with another issue. By identifying concessions that each party could potentially make and rating them as to how they addressed each of the identified issues, we reached an outcome whereby certain actions could be seen to be more productive than others. This is achieved either by bundling concessions on one side to address issues raised by the other side or identifying issues that cannot be traded off by amassing concessions from one party, mainly because some of the issues are so fundamental to the negotiations that no number of concessions could balance their importance. While some of these conclusions may be apparent to the concerned observer, the process provides affirmation of the conclusions.

While the casual observer might suggest critically that the conclusions and outcomes of the study were totally dependent on what the positions of the participants on the negotiating team were, we believe that this is indeed an accurate conclusion but does not in any way invalidate the study. The outcomes depend on the judgments made and the judgments depend on the opinions of the negotiators. It is self evident that who does the negotiating will directly affect the outcome. We are less concerned with coming to any particular solution than we are with demonstrating how the AHP represents an approach that captures reality without the burden of excessive emotion. Ultimately, solutions that emerge from the process will depend on the positions and attitudes of the negotiators. To the extent that the negotiators represent positions which encompass varying proportions of the constituencies they represent, the solution will either be arrived at within a reasonable time period, or after extended lengthy discussions, possibly never arriving at a solution. Our recommendations noted below include our response to this phenomenon.

It is important to understand that the process has two major components, the first being the identification of issues, concessions, benefits and costs to each side and a second which concerns implementation policies. This simulation covered only the first stage of the process. So what was the outcome? We believe there were eight important conclusions that we could draw.

They are as follows;

1. The exercise validated that our process made it possible to consider the potential concessions each side might make and to consider the tradeoffs of such concessions, either individually or in bundles. The participants learned how to trade off such concessions to serve the interests of both parties. They identified 27 concessions, fourteen from one side and thirteen from the other. We do not have any reason to believe that this included every possible concession that might be made. Since the AHP process requires that everything possible be considered for inclusion in the structure: the issues and their concessions, with benefits and costs, it is recommended that every effort be made to include the full range of issues and concessions. In our simulation, we may well

have overlooked one or more of these issues and concessions and thus our structure may be incomplete. That in no way diminishes the effectiveness of our simulation. However, before beginning to work with combinations of concessions to trade them off, the structure can be trimmed down to include only what are now known to be the major elements.

2. The outcome in many cases reinforced the conventional wisdom of the participants as to what the concrete objectives of each side are and what positions either side is willing to modify with concessions from the other side or is not willing to modify regardless of the other side's concessions. But it was now possible to measure the gains and losses related to various concessions as identified by the party that would be providing the concessions as well as their judgment as to what the benefits and costs were to the other party in providing their concessions. Obviously the opinion of one side about the costs and benefits to the other side of specific concessions sometimes varied widely from the other side's opinion as to the costs and benefits to them of the concessions they might possibly make. These differences in perception are revealing and they often led to differences in gain-to-loss ratios as perceived by each party.
3. The AHP process made it possible for the participants to consider a wide variety of potential tradeoffs, either individually or in bundles. By attaching quantitative values to the comparisons, a great deal of the emotionality of the discussion was defused. It became clear that, at least in the case of these specific participants, certain issues appeared not to be tradable or that the participants did not know how to trade them. For example, the Israeli need to have a Jewish state and the Palestinian need to have a satisfactory solution to the resettlement of refugees appeared to be issues which could not be easily compromised, if at all. One might surmise that solutions to such issues might require the involvement of outside parties and that solutions not totally acceptable to either side might have to be imposed. By comparing costs and benefits of concessions as viewed by either party and establishing hierarchies which permitted comparisons of the issues and concessions, some equivalence of pain or cost and of benefit, either by individual comparisons or in bundles, might suggest a reasonably objective statement of what a "fair" or equally painful or equally beneficial outcome might be. Neither side might feel such a solution would be a "win" for them, an objective each side would prefer to achieve. They might be convinced, perhaps only by outside parties, that a solution that would bring peace could only be achieved if each party recognized through a process such as the AHP or otherwise, that trading off a similarly beneficial and painful (as objectively measured) set of solutions is the only way to achieve peace. A further advantage would be that outside parties, such as the United States or the European Union or the United Nations, etc. could pressure the parties to settle, using solutions carefully balanced to favor neither side and exacting compromises from both sides that these outside parties could feel reasonably comfortable that their impact was objectively measured.
4. Participants were willing to talk about sensitive issues as part of the concession discussion without feeling threatened by the other party. Though the

participants occasionally engaged in heated discussions, in general, an order of civility was engendered. The participants were concerned with looking at issues at a micro level rather than a macro level, with comparisons of priorities, establishment of hierarchies, weighting of judgments considered on an issue-by-issue and concession-by-concession basis. This did not necessarily change the emotionality that each side felt, but by separating the issues and the concessions, participants were encouraged to consider the relative importance of one issue and the effect upon it of one or many concessions. It is obviously an over simplification to suggest, that by breaking the problem into small pieces and then working to measure judgments mathematically, that participants were so engaged in collating relevant tasks that their emotionality largely disappeared. To continue the analogy, participants had cut the puzzle into a jigsaw of tiny pieces where the total picture was not discernible as they decided which piece fit into which other piece. But when the pieces were put back together, the puzzle might look somewhat different. The complete puzzle from this experiment has not yet been put together for a variety of reasons, but when it is, it is fairly certain that it will offer a somewhat different path for proceeding than has been the case thus far. The main reason the puzzle remains in pieces is that we have not yet focused on the second stage of the process where implementation strategies will be defined and there are still some parts of the initial process such as defining the issues and the concessions in more definitive terms that need to be redone and reconsidered based on our experience so far.

5. A major outcome of the process thus far is that the parties have identified 106 issues and numerous concessions as being relevant to their deliberations. We have arbitrarily grouped these issues and concessions into major categories. The richness of the issues in each category as well as the grouping of the concessions has helped to define the issues and concessions more exactly. This approach provided a structure where participants have decomposed the problem rather than seeking immediate solutions. What the parameters of the problem were was one question addressed. What actions the parties could potentially take to address these issues was a second questioned answered. In each session we spent only three days for the entire process in this effort, so we cannot suggest that every possible concession and issue was identified. But we do believe that some issues are multi-faceted and what was suggested as a separate issue may turn out to be a part, large or small, of another issue. A major outcome was that by examining the issues in contention and the concessions that might address one or many of those issues, the importance of the issues and concessions in terms of gains and losses as perceived by each party were represented by mathematical judgments and quantified.
6. A crucial finding is the need to identify and develop implementation policies for all the concessions. For example, there was much discussion about a possible compromise by the Palestinians on their demand for the right of return of those Palestinians originally living in what is now part of Israel. But without an implementation policy or a set of options, if there is more than one possibility, the mere statement of offering such a concession is ineffective without finding

offsetting compromises and policies that would likely be difficult to implement. The process we engaged in has generally identified the issues where implementation policies are necessary. In some of these cases, concessions cannot be provided by the actions of the party alone offering the concession. There need to be other parties involved and willing to play a part so that the concession is truly on the table and a trade can be achieved. The question of how could this concession be achieved must be answered before the concession becomes viable. We still need to examine each concession and determine by participant involvement just what will be required and by whom to make that concession a real possibility.

7. An important outcome of this effort was to identify what the parties meant by the use of certain terms. For example, we now know that the use of the words "human rights" which came up time and time again in the discussions is not easily defined. It means one thing to the Palestinians and something else to the Israelis. How human rights are identified, displayed, defined, executed, and implemented needs to be discussed in some detail. Participants cannot make effective judgments about such terms when they are being mathematically compared with other terms, if the sides have different definitions of the terms. The limitations of time made it impossible to engage in the complex discussions that would have been required to address this matter. Another example is what is exactly meant by the "sharing of Jerusalem". It is again important to emphasize that this problem in no way interfered with the basic question we posed, which was how could the Israeli–Palestinian question be fitted into the AHP structure and would the process be amenable to using the AHP approach. We did not expect a solution to emerge, but as the process is further employed and the next stage of discussions occur and perhaps later as the participants in the study are actual negotiators, the outcomes will perhaps yield some promising avenues for negotiation not yet in play.
8. The experiment we conducted convinced us that a reasonably timed conclusion to the conflict would be substantially enhanced if the negotiators represented the viewpoint of some predetermined proportion of their respective constituencies. Recognizing that a suggestion of some non-inclusiveness in the discussion in the interest of expediency is not only controversial but likely to elicit all sorts of opprobrium, there is one other way to achieve the same result. It is complex and may produce similar outcries, but at least it is an alternative. If we could determine, by survey or otherwise, what the proportion in each society was of far right, far left and center positions, we could use the AHP process (which would weight the judgments based on the proportion of that society the negotiator represented) so that intractable positions are minimized, understanding that someone would need to deal with the anger from those whose judgments were considered less crucial to a final solution because they represented a smaller proportion of their respective populations.

A major stumbling block in the negotiations attempted to date results from the determined effort to address all of the issues in a single format, in one place, in a comprehensive manner. Results of our experiment suggest that it would be far more feasible to address a few of the issues and concessions at a time.

During these discussions the Palestinian representatives indicated that they felt strong anger because of their perception that Israel has not taken more responsibility in helping to solve the Palestinian refugee problem. The Israeli representatives, on the other hand, expressed their sense of anger because the Palestinians failed to participate in helping the Israelis to obtain the level of security which is essential to move the process forward from the Israeli position.

In summary these meetings yielded positive but preliminary results that are clearly inconclusive and incomplete. Nothing that has occurred invalidates the efficacy of the AHP as a novel and comprehensive approach to solve this problem. It needs to be carried to its ultimate conclusion including addressing the definition and implementation concerns using actual negotiators to release the power of the process.

While the foregoing general outcomes represent important progress, the capacity of this process to yield useful conclusions that would move the dialogue forward depends on using the results to identify specific steps that could constitute a new start to the discussions. We also need to examine what remains to be done. Clearly, the approach taken seems to work well to address the problem. But as the effort continued it became clearer as to what needs to be done in the next round of discussions.

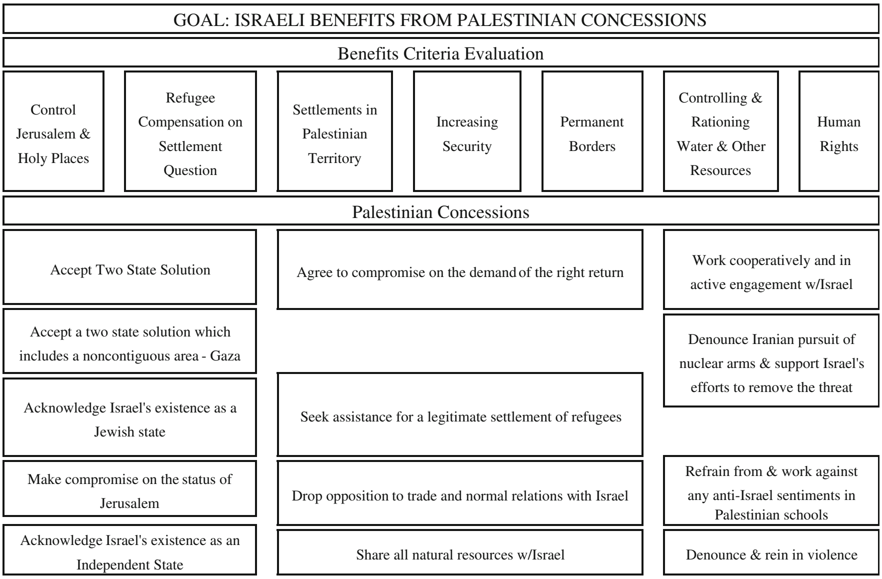
We need to identify those terms where definitions are crucial and work out agreed upon statements of exactly what those words or terms meant in order to permit judgments and comparisons that are more accurate. We also need to identify which areas of concessions need implementation policies developed to make them viable and to examine as many options as possible in considering the implementation.

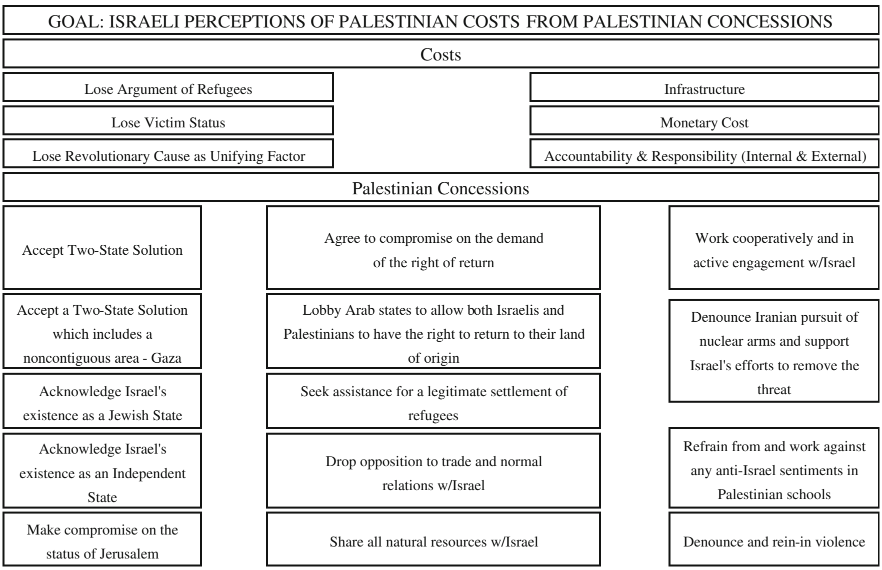
In summary, our participants identified more than 100 issues of small and large import which were viewed as necessary to address if the Palestinian–Israeli conflict is to be resolved. In the few days available to them, they identified a significant number of concessions both sides could offer, if they were willing to do so, which would address most of these issues. To the extent not all issues were addressed by possible concessions, it was either because the issues were trivial and not worthy of specific concessions or time or imagination did not permit the identification of appropriate concessions to address those particular issues.

The panel was able to trade-off all but two major issues (a secure, independent democratic Jewish state recognized by the Palestinians and a solution to the resettlement of refugees). These two issues would need to be considered in a separate application of AHP to find the difficult concessions necessary to tradeoff concessions that would meet our restrictions and still address those two issues directly. That process remains to be addressed.

To date the official negotiations have not produced a viable solution. Our research suggests that by organizing the concerns in a more effective way, identifying concessions that would address the issues identified, assuming both sides see an advantage in a peaceful resolution quickly, measuring both tangible and intangible factors, draining the emotions out of the discussions to the extent possible, and decomposing the issues into manageable segments, all of which is possible through the use of the Analytic Hierarchy Process, a chance of resolution is enhanced. What have the parties got to lose?

Appendix 1





GOAL: ISRAELI PERCEPTIONS OF PALESTINIAN GAINS FROM ISRAELI CONCESSIONS

Gains

International	Recognized Borders	Independence	Law & Order
Member of Nations	Peace	Economic Trade	Pride

Israeli Concessions

- Abandon the idea of a Jewish State
- Accept a two-state solution
- Comply w/all applicable United Nations resolutions
- Allow the sharing of all natural resources between Palestinians and Israelis
- Allow all parties to have equal access to and control of religious sites and holy places
- Share Jerusalem as both a religious & political center w/all parties
- Turnover settlements of Jewish settlers on land claimed by the Palestinians with or without compensation
- Comply w/human rights
- Implement Palestinian refugee rights
- Encourage equal opportunity for Palestinians to achieve equal economic prosperity
- Allow the right to have an education that is non-biased and equally shares historic backgrounds
- Permit Palestinian freedom of movement
- Remove the wall and other barriers to Palestinian movement

GOAL: ISRAELI COSTS FROM OWN CONCESSIONS

Israeli Cost Criteria Evaluation

Economic	Political	Religious	Psychological	Security	International Image	Demographic
Administration (Law & Order)		Civil Disorder (War)		Social	Unification of Jewish People	

Israeli Concessions

- Abandon the idea of a Jewish State
- Accept a two-state solution
- Comply w/all applicable United Nations resolutions
- Allow the sharing of all natural resources between Palestinians & Israelis
- Allow all parties to have equal access to and control of religious sites and holy places
- Share Jerusalem as both a religious & political center w/all parties
- Turnover settlements of Jewish settlers on land claimed by the Palestinians with or without compensation
- Comply w/human rights
- Implement Palestinian refugee rights
- Encourage equal opportunity for Palestinians to achieve equal economic prosperity
- Allow the right to have an education that is non-biased and equally shares historic backgrounds
- Permit Palestinian freedom of movement
- Remove the wall & other barriers to Palestinian movement

GOAL: PALESTINIAN BENEFITS FROM ISRAELI CONCESSIONS

Benefits Criteria Evaluation

- Human Rights
- Freedom of Movement
- Permanent Borders
- Shared Water & Other Resources
- Sovereign Palestinian State
- Resolution of the Refugee Problem
- Vacating of Israelis from Settlements in Palestinian Territory
- Two-Way Compensation
- Shared Control of Jerusalem & Holy Places
- Security

Israeli Concessions

- Abandon the idea of a Jewish State
- Accept a two-state solution
- Comply w/all applicable United Nations resolutions
- Allow the sharing of all natural resources between Palestinians & Israelis
- Allow all parties to have equal access to and control of religious sites & holy places
- Share Jerusalem as both a religious & political center w/all parties
- Turnover settlements of Jewish settlers on land claimed by the Palestinians with or without compensation
- Comply w/human rights
- Implement Palestinian refugee rights
- Encourage equal opportunity for Palestinians to achieve equal economic prosperity
- Allow the right to have an education that is non-biased & equally shares historic backgrounds
- Permit Palestinian freedom of movement
- Remove the Wall & other barriers to Palestinian movement

GOAL: PALESTINIAN PERCEPTIONS OF ISRAELI COSTS FROM ISRAELI CONCESSIONS

Costs

- Ending Superiority (Attitude & Practical)
- Change of Zionist Narrative
- Property Restitution & Compensation
- Settlement Evacuation
- Social Restructuring
- Unity Based on Common Identity

Israeli Concessions

- Abandon the idea of a Jewish State
- Accept a two-state solution
- Comply w/all applicable United Nations resolutions
- Allow the sharing of all natural resources between Palestinians & Israelis
- Allow all parties to have equal access to and control of religious sites and holy places
- Share Jerusalem as both a religious & political center w/all parties
- Turnover settlements of Jewish settlers on land claimed by Palestinians w/or without compensation
- Comply w/human rights
- Implement Palestinian refugee rights
- Encourage equal opportunity for Palestinians to achieve equal economic prosperity
- Allow the right to have an education that is non-biased & equally shares historic backgrounds
- Permit Palestinian freedom of movement
- Remove the Wall & other barriers to Palestinian movement

GOAL: PALESTINIAN COSTS FROM OWN CONCESSIONS

Palestinian Costs from Their Own Concessions

Political	Psychological	Quality of Life	Challenging Israel	Access to Resources	Identity
Economic	Religious	International Image	Property Rights	Access to Family Ties	Moral
Land/Sea Control	Social	Social Harmony	Public Standing	International Standing	Divisio n

Palestinian Concessions

- Accept Two-State Solution
- Accept a Two-State Solution which includes a noncontiguous area - Gaza
- Acknowledge Israel's existence as a Jewish State
- Acknowledge Israel's existence as an Independent State
- Make compromise on the status of Jerusalem
- Agree to compromise on the demand of the right of return
- Lobby Arab states to allow both Israelis & Palestinians to have the right to return to their land of origin
- Seek assistance for a legitimate settlement of refugees
- Drop opposition to trade & normal relations w/Israel
- Share all natural resources w/Israel
- Work cooperatively & in active engagement w/Israel
- Denounce Iranian pursuit of nuclear arms & support Israel's efforts to remove the threat
- Refrain from and work against any anti-Israel sentiments in Palestinian schools
- Denounce & rein-in violence

GOAL: PALESTINIAN PERCEPTIONS OF IS RAELI GAINS FROM PALESTINIAN CONCESSIONS

Benefits

- Peace of Mind (Security, Defense, Hostility)
- Retention of Israeli Immigration
- Acceptance of Israel with Islamic World
- Social Harmony
- Reduce Fear of Living
- Leveraging Resources
- Acceptance of Israelis
- Sharing of Religious Festivals
- Ending of Apartheid of Israel
- Sharing of Religious Festivals
- Trade within a Region

Palestinian Concessions

- Accept Two-State Solution
- Accept a Two-State Solution which includes a noncontiguous area - Gaza
- Acknowledge Israel's existence as a Jewish State
- Acknowledge Israel's existence as an Independent State
- Make compromise on the status of Jerusalem
- Agree to compromise on the demand of the right of return
- Lobby Arab states to allow both Israelis & Palestinians to have the right to return to their land of origin
- Seek assistance for a legitimate settlement of refugees
- Drop opposition to trade & normal relations w/Israel
- Share all natural resources w/Israel
- Work cooperatively & in active engagement w/Israel
- Denounce Iranian pursuit of nuclear arms & support Israel's efforts to remove the threat
- Refrain from and work against any anti-Israel sentiments in Palestinian schools
- Denounce & rein-in violence

Appendix 2: How to Select Concessions from One Party to Match Concessions from Another Party

To decide how to match the concessions of one party with the concessions from another party we need to first create all possible concession bundles for both parties. A concession bundle is a set of individual concessions. The parties can then trade concession bundles. The problem is that there are many possible concession bundles even when the parties in conflict have a moderately small number of possible concessions. For example if one party had 13 concessions and another had 14 concessions, there are 8,191 and 16,383 possible concession bundles, respectively. Since we need to match a bundle of one party with all other possible bundles of the other party, to determine which concession bundle is more advantageous, we need to solve 7,563 matching problems for one party and 14,787 problems for the other party. Were we to do it all at once, then the problem would be even more difficult to solve, because the problem would involve 8,191 $\times$ 16,383 = 134,217,728 variables. A possible solution is to divide the concessions into groups such as short, medium and long term sets and then form the bundles.

Let $C_A$and C_B be the set of concession bundles of two parties A and B in a conflict. Let $c_i(k)$ be the ith concession bundle of party k. Let $p(i,A|j,B)$ be the ratio gain from the ith concession bundle of party A when party B offers the jth concession. Let $q(j,B|i,A)$ be the ratio gain from the jth concession bundle of party B when party A offers the ith concession. Let x_{ij} be a binary variable where $x_{ij} = 1$ if the ith concession bundle of A is matched with the jth concession bundle of B.

Concession bundles from one party can be paired with concessions bundles of the other party. Thus, the total gain of party A is given by $\sum\limits_{i\in C_A}\sum\limits_{j\in C_B} p(i,A|j,B)x_{ij}$ and the total gain of party B is given by $\sum\limits_{i\in C_A}\sum\limits_{j\in C_B} q(j,B|i,A)x_{ij}$. To balance both gains and provide both parties with the maximum gain, we solve a MaxMin problem, i.e., a maximization model whose objective function is an arbitrary variable x_0 such that $\sum\limits_{i\in C_A}\sum\limits_{j\in C_B} p(i,A|j,B)x_{ij} \geq x_0$ and $\sum\limits_{i\in C_A}\sum\limits_{j\in C_B} q(j,B|i,A)x_{ij} \geq x_0$. If all the concessions are matched then $\sum\limits_{i\in C_A} x_{ij} = 1$ and $\sum\limits_{j\in C_B} x_{ij} = 1$. If only a subset of $S_A \subset C_A$ is matched with C_B then $\sum\limits_{j\in C_B} x_{ij} = 1$, for $i \in S_A$ and $\sum\limits_{i\in C_A} x_{ij} \leq 1$. If only a subset $S_A \subset C_A$ is matched with a subset $S_B \subset C_B$, then $\sum\limits_{j\in C_B} x_{ij} \leq 1$ for $i \in S_A$ and $\sum\limits_{i\in C_A} x_{ij} \leq 1$ for $j \in S_B$. Thus the more general problem is given by:

$$
\begin{aligned}
&\quad Max\, x_0\\
&\text{s.t.,}\\
&\quad \sum_{i\in C_A}\sum_{j\in C_B} p(i,A|j,B)x_{ij} \geq x_0\\
&\quad \sum_{i\in C_A}\sum_{j\in C_B} q(j,B|i,A)x_{ij} \geq x_0\\
&\quad \left|\sum_{i\in C_A}\sum_{j\in C_B} p(i,A|j,B)x_{ij} - \sum_{i\in C_A}\sum_{j\in C_B} q(j,B|i,A)x_{ij}\right| \leq \varepsilon\\
&\quad \sum_{j\in C_B} x_{ij} \leq 1, \quad i \in S_A\\
&\quad \sum_{j\in C_B} x_{ij} = 0, \quad i \notin S_A\\
&\quad \sum_{i\in C_A} x_{ij} \leq 1, \quad j \in S_B\\
&\quad \sum_{i\in C_A} x_{ij} = 0, \quad j \notin S_B\\
&\quad x_{ij} = 0, 1, \quad i \in C_A \text{ and } j \in C_B
\end{aligned}
$$

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Chapter 16
Legalization of Euthanasia

16.1 Introduction

The Oxford English Dictionary (2nd edition, 1989; online version June 2011) provides the following definitions of euthanasia:

> A gentle and easy death… The means of bringing about a gentle and easy death… In recent use: The action of inducing a gentle and easy death. Used esp. with reference to a proposal that the law should sanction the putting painlessly to death of those suffering from incurable and extremely painful diseases.

According to ProCon.org (http://euthanasia.procon.org/): "Proponents of euthanasia and physician-assisted suicide (PAS) contend, that terminally ill people should have the right to end their suffering with a quick, dignified, and compassionate death. They argue that the right to die is protected by the same constitutional safeguards that guarantee such rights as marriage, procreation, and the refusal or termination of life-saving medical treatment. Opponents of euthanasia and physician-assisted suicide contend that doctors have a moral responsibility to keep their patients alive as reflected by the Hippocratic Oath. They argue there may be a "slippery slope" from euthanasia to murder, and that legalizing euthanasia will unfairly target the poor and disabled and create incentives for insurance companies to terminate lives in order to save money."

The controversy over the legalization of euthanasia is being debated nationally, from the halls of Congress to hospital corridors. The ramifications of possible legalization have many groups scrambling to either enforce it or stop it. Although the media has not given euthanasia much air time, the issue is still in the forefront of the minds of the populous. Several states have proposed legislation to legalize assisted suicide. The state of Oregon put this on a ballot and the voters passed the bill in 1996. Soon thereafter, an injunction was filed by a right to life organization questioning the constitutionality of the bill. In 2006 the United States Supreme Court upheld a lower court ruling that found that Oregon's Death With Dignity Act protected assisted

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suicide as a legitimate medical practice. The differentiation between passive and active euthanasia and assisted suicide is a very important one. Passive euthanasia is what is currently being practiced in most states. If a patient no longer wishes to receive medical care, then doctors abide by his or her wishes by foregoing medication, withholding hydration and nutrition, or "pulling the plug" on a breathing apparatus. The patient may legally express these wishes in a living will or advance directive. Assisted suicide refers to doctors possibly prescribing medication to end patient's lives, but the medication would be administered by the patient. Active euthanasia entails the doctors taking an active role by actually injecting a lethal solution into the patient's bloodstream. Many people believe the latter to be murder, but are more tolerant toward the former alternatives. Dr. Jack Kevorkian tested the legality of assisted suicide many times, and was brought to trial on several occasions. He spent eight years in prison after being convicted of second-degree murder in the death of the last of about 130 ailing patients whose lives he had helped end, beginning in 1990. The people whose lives he assisted in ending were all terminally ill, and requested his help. Dr. Kevorkian's rationalization for assisted suicide is that if the patients request to die, who are "we" to deny them? He and other advocates of euthanasia and assisted suicide believe it to be an issue of individual rights and patient autonomy, and also wish to exempt physicians who participate in this activity from potential criminal prosecution. The medical community is divided on this issue because many physicians believe it violates the Hippocratic Oath: "I will give no deadly medicine to anyone if asked, nor suggest any such counsel" [1]. However, they do not wish to prolong suffering if the patient is terminally ill and wishes to die. Some doctors currently perform a version of assisted suicide, prescribing increasing doses of morphine to terminally ill patients—effectively sedating them to death [2]—while others refuse to break their promise to uphold life at any cost. The possible legal ramifications of legalizing euthanasia are far-reaching. Many foes of assisted suicide believe that there would be a great potential for abuse on the part of physicians. This would probably necessitate the formation of a new government agency which would monitor physicians—a costly endeavor. Many people in the religious community have contested the reasoning of patient autonomy by stating that patients may not be in rational state of minds when making the decision to end their lives [3]. Another issue is the objective measurement of suffering. Who is to make the distinction between the suffering of a terminally ill cancer patient and a depressed teenager? If the latter is protected from assisted suicide, why not the former? Right to life advocates also list the improvements that may be gained from therapy, counseling, analgesia, and pastoral practice as conceivable alternatives to taking one's life.

As of 2011, there is no specific federal law regarding either euthanasia or assisted suicide. All 50 states and the District of Columbia prohibit euthanasia under general homicide laws. Assisted suicide laws are handled at the state level: Of the 50 states: 36 states have specific laws prohibiting all assisted suicides; seven states prohibit all assisted suicides under common law; four states (and the District of Columbia) have no specific laws regarding assisted suicide, and do not recognize common law in regard to assisted suicide; and only three states, Oregon, Washington, and Montana, have legalized physician-assisted suicide.

16.2 The Analytic Hierarchy Model

The legalization of euthanasia is a highly charged political issue. Like many other political issues, its fate is determined by key players—politicians, the general public, and strong lobbying groups—and their view of the major issues within the dilemma. The model used to answer the question of whether or not euthanasia should be legalized is the benefit—cost analytic hierarchy. The risks associated with the legalization of euthanasia are incorporated in the cost hierarchy because, in a life-critical situation, all risks inevitably become costs. Because we are not at liberty to gamble with human life, we must assume the worst case scenario and take all risks to be costs. The key players surrounding this issue are the criteria and the key issues they face are the subcriteria, followed by the alternatives.

16.2.1 Key Players

Politicians—Politicians play a critical role in that members of congress would be the ones to pass the legislation necessary to legalize euthanasia or assisted suicide. The decision not to divide this criterion into Republican and Democrat subcategories is due to the fact that euthanasia is not a bipartisan issue.

General Population—The population at large plays the most important role in this model because they influence all of the other key players in that they elect politicians or they can boycott certain hospitals who refuse to perform the procedure and those who do perform the procedure. This criterion was divided along racial lines because different ethnic groups react and feel differently about this subject.

Religious Groups—A third group that bears a powerful political voice and has expressed strong views on the subject of euthanasia is religious groups. There is a strong Catholic influence in the U.S., and we felt that this group's opinions would have a significant influence on the outcome. The stance of the Catholic Church is adamantly opposed to both assisted suicide and euthanasia. However, passive euthanasia is not condemned [4]. The second subgroup which has become quite a strong political force is the Religious Right. In the past few years, their number has grown tremendously and their influence is being felt on the political level. We understand that the majority of the US population belongs to Protestant, Jewish, and other faiths, but their voices on the issue of euthanasia have not been strongly heard. Because their influence on the decision was minute, we have excluded them from the hierarchy.

American Medical Association—The AMA is at the center of this issue because doctors would play a major role in the decision to terminate life. In the past, the AMA has vehemently opposed assisted suicide and active euthanasia [5] because they directly contradict the Hippocratic Oath. More recently, however, the AMA has moderated its position in response to the increasing number of physicians who support the measures. The AMA is a powerful political lobbyist, and therefore placed third in overall ranking of key players.

Hemlock Society—In our model, the Hemlock Society represents all right-to-die groups. The Hemlock Society has been in existence for over twenty years and its members are very vocal in support of all forms of euthanasia. Although the group placed last in the rankings, its influence should not be ignored. An organization like the Hemlock Society placed the assisted suicide bill on the ballot in Oregon in 1996.

16.2.2 Kev Issues

16.2.2.1 Benefits Hierarchy

Economic—Medical costs incurred by patients for hospitalization and terminal care would be significantly reduced, and the limited resources available to fund such care would not be as strained. Approximately 80% of a patient's lifetime medical expenses are incurred in the last three weeks of life—mostly because of the high costs of life support and intensive care [6]. Economic issues are considered by all of the key players with the exception of Religious groups and the Hemlock Society.

Moral/Ethical—The moral benefits of euthanasia refer to the people's perception of euthanasia as mercy killing, and the ethical nature of obeying a terminal patient's last wishes. Under the benefits hierarchy, the moral priority would be to relieve terminally ill patients from suffering a long and painful death.

Legal—It has been argued that the constitutional guarantee of individual liberty includes the right to seek aid in dying [7]. The decision to end one's own life is one of the most intimate and personal choices a person may make in a lifetime. These choices, central to an individual's autonomy and personal dignity, are central to the liberty protected in the 14th Amendment [8]. The legalization of assisted suicide and active euthanasia will guarantee the freedom to exercise this right.

Patient Concerns—This subcriterion encompasses the personal dignity, autonomy, and self-determination which follows through the course of an individual's life, and should accompany death. Some believe that the legalization of assisted suicide or active euthanasia will improve compassionate care at the end of life [9]. Doctors feel helpless in the face of terminal illness, and the dying patient perceives this helplessness as abandonment. Euthanasia would increase the patient's autonomy and control, reduce pain, and a1low for the proper termination of life under a physician's guidance.

16.2.2.2 Costs Hierarchy

Economic—As with any medical procedure, assisted suicide and active euthanasia will involve some financial costs. These may include the cost of a prescribed drug overdose for assisted suicide or fees paid to the attending physician for active euthanasia. The increase in medical malpractice liability should also be considered, and although current malpractice insurance is likely to cover euthanasia suits [10], it is also likely that the legalization of euthanasia will drive up the cost of malpractice insurance to doctors and hospitals.

Moral—Refers to the notion of whether it is morally right to take one's own life and for someone else to assist this endeavor. This criterion weighted heavily with the general population and with religious groups.

Legal—This subcriterion looks at the possible lawsuits that medical profession could face for potential abuses of the system, and for an unwillingness to participate in assisted suicide. In addition, physicians may face liability in cases of assisted suicide where the drug overdose did not cause the patient to die. As many as a quarter of those who try to kill themselves with a prescribed overdose could linger for hours or days before they died [11]. The legal costs also refer to an increase in legal activity in the government due to necessary legislation to pass this bill and regulate its use.

Patient Concerns—The major cost in patient concerns in assisted suicide is the risk of failed procedure. Because doctors are not trained in terminating life, their "fatal" prescriptions come with no guarantees. Patients who take an insufficient dose could suffer increased pain and incapacitation. In addition, there is the risk that the patient is not mentally fit to make the decision to seek assisted suicide or active euthanasia. Many people who seek to commit suicide are motivated by depression, mental illness, or emotional distress, rather than by a rational evaluation of the situation and subsequent logical decision. A final cost is the families' potential difficulties in accepting this decision.

16.2.2.3 Alternatives

Status Quo—The current acceptable practice is passive euthanasia where a physician may withhold medical services at the patient's request.

Assisted Suicide—This alternative would allow physicians to prescribe medication which patients would self-administer.

Active Euthanasia—This is the extreme of all of the alternatives where a doctor would lethally inject a terminally ill patient.

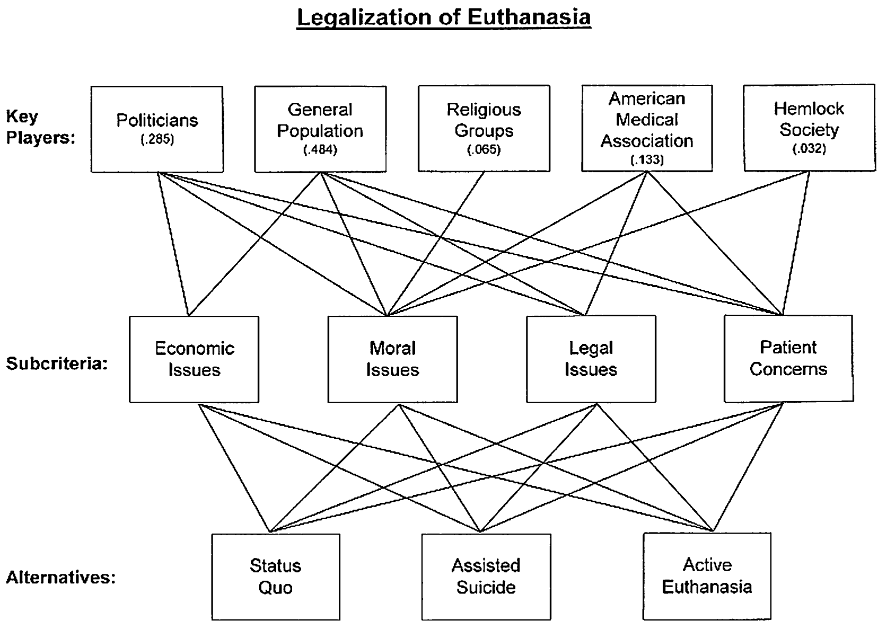


Fig. 16.1 Legalization of euthanasia hierarchy

16.2.2.4 Model Assumptions

Prior to evaluating the criteria, we made several assumptions:

1. This is a political issue in that without proper legislation, none of these alternatives would be legal, and therefore would be deemed impossible.
2. All of the key players are essentially lobbyists who must attempt to convince congress to act appropriately depending on each group‘s stance.
3. Terminally ill patients and their families are represented in the general population as well as the other groups. We did not list them as a key player because they are not a unified, politically active entity. In addition, if we had divided the general population into subsets of people in favor Of euthanasia and people against euthanasia, our end result would not be as objective.
4. The only subcriterion that religious groups are concerned with is the moral issue. These groups are not affected by possible economic or legal ramifications, and they do not have a substantial voice on patient concerns. Therefore, we deleted all subcriteria within the religious groups except for the moral/ethical issue.

Figures 16.1, 16.2, 16.3, 16.4, 16.5, 16.6, 16.7, 16.8, 16.9, 16.10, 16.11 show the benefits and costs hierarchies as well as the priorities assigned to the criteria and the priorities of the alternatives under each criterion.

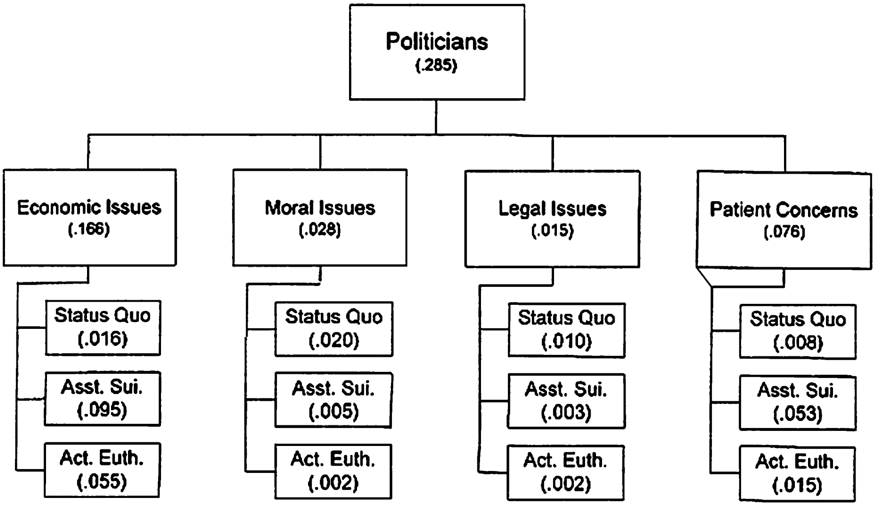


Fig. 16.2 Politicians' benefits hierarchy

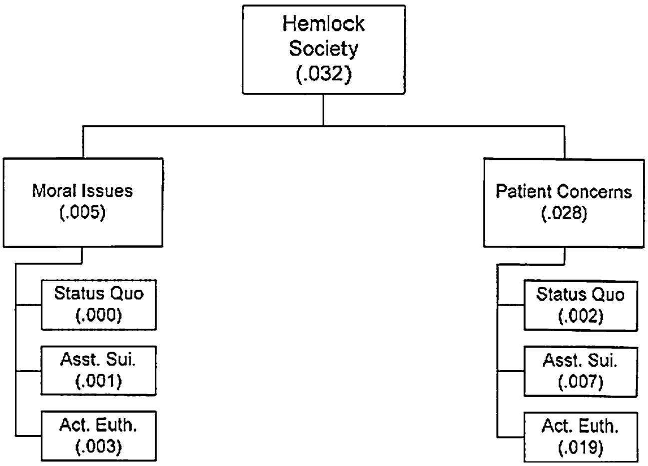


Fig. 16.3 Hemlock society's benefits Hierarchy

16.3 Results

Table 16.1 summarizes the points of view of the different constituencies. Note that Politicians, the general population and the AMA think that *Assisted Suicide* has the most benefits while religious groups and the Hemlock society find themselves at opposite extremes. In terms of costs, everybody but the Hemlock society think that active euthanasia is most costly

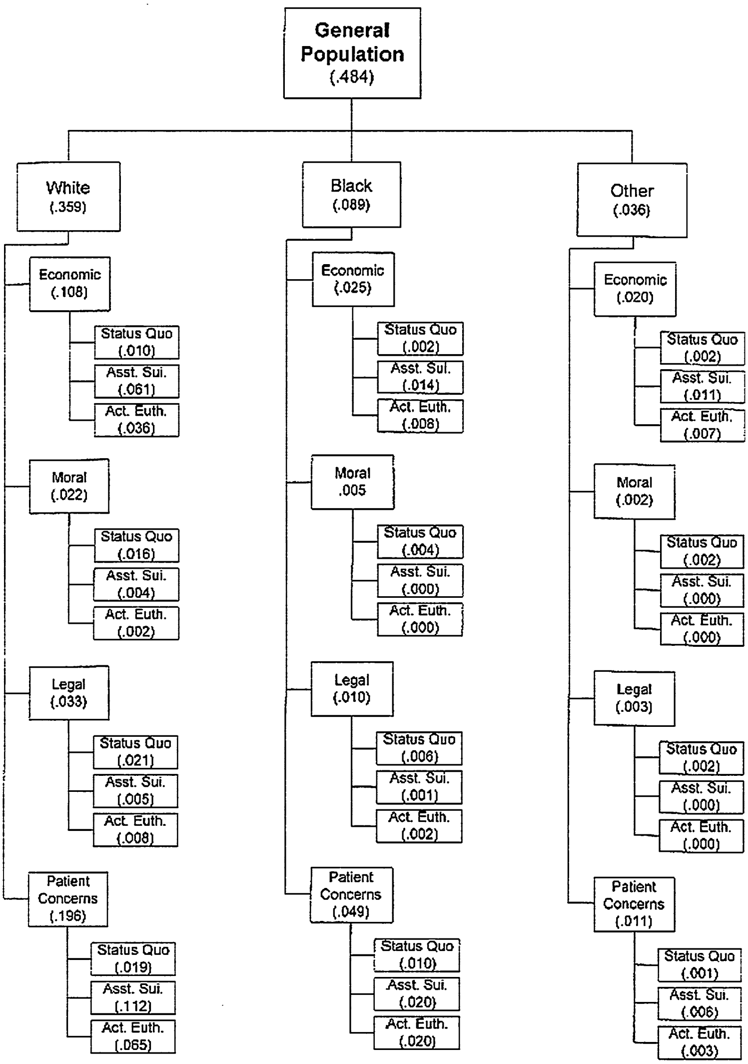


Fig. 16.4 General population's benefits hierarchy

The final result is to keep the status quo, although assisted suicide was a close second and active euthanasia finished a distant third. The final decision is not surprising and reflects people's unwillingness "to rock the boat". Most people would rather avoid making such a choice because of the delicacy of the issue. No one really wants to face death and no one wants to play God. We believe the moral/ethical issue played the biggest role of all the subcriteria in the final decision because it is the most ambiguous. Costs and benefits values can easily be measured

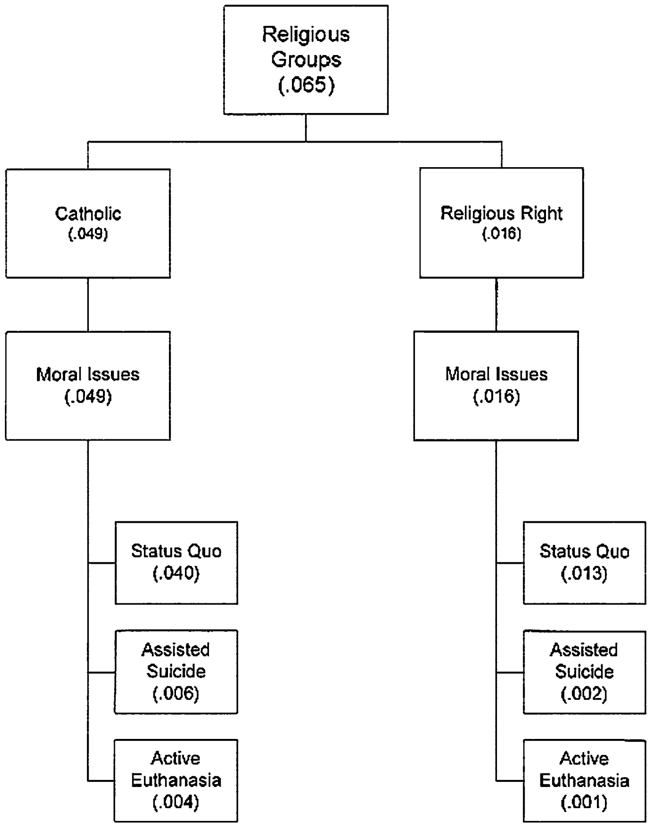


Fig. 16.5 Religious groups' benefits hierarchy

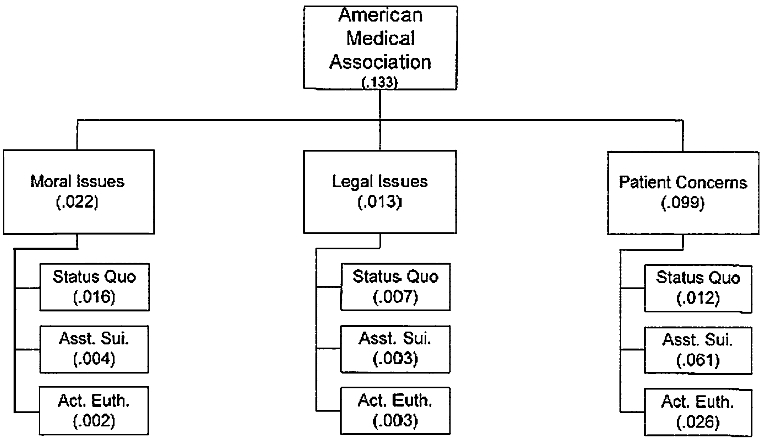


Fig. 16.6 AMA's benefits hierarchy

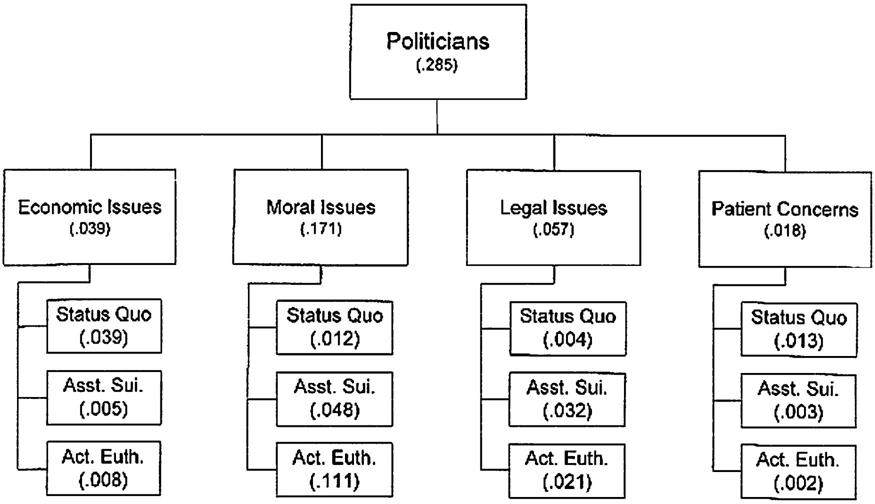
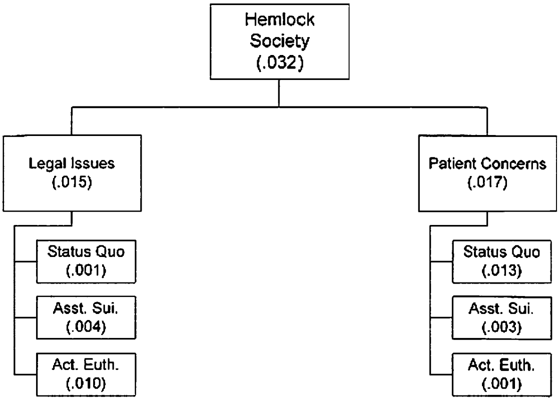


Fig. 16.7 Politicians' costs hierarchy

Fig. 16.8 Hemlock society's costs hierarchy



for economic and legal issues, while in the cases of moral/ethical and patient concerns, value is very much subjective. Finally, the country seems to be heading in conservative direction, and maintaining the status quo confirms that trend.

16.4 Sensitivity Analysis

To determine the strength and resilience of our model, we must conduct sensitivity tests. Although this is an issue of national importance, we expect that different regions within the U.S. would impose varying degrees of latitude on euthanasia. In our sensitivity analysis, we looked at Western states, Southern states, and the Pittsburgh area. Our results are given in Table 16.2, 16.3 and 16.4.

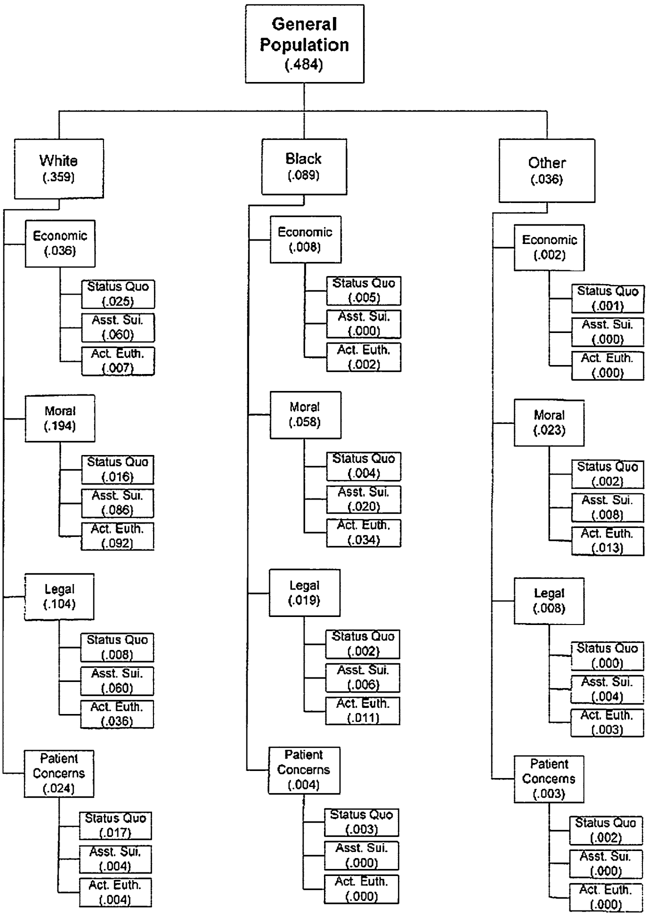
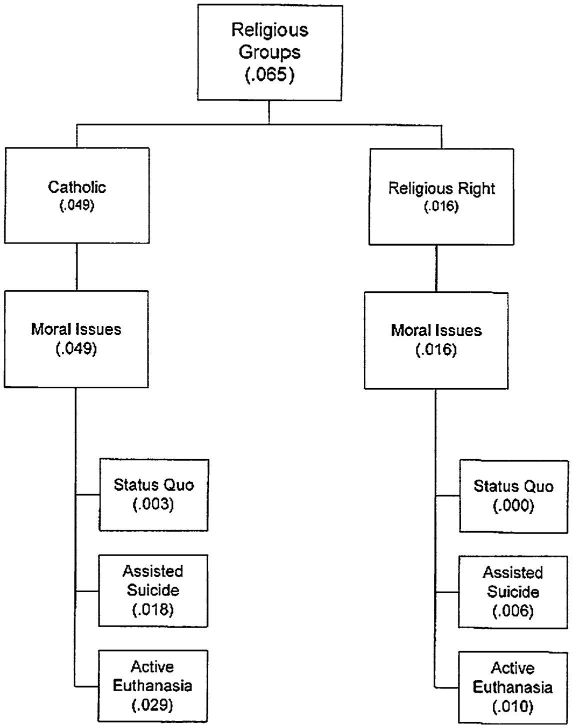


Fig. 16.9 General population's costs hierarchy

In our analysis for the West, we incorporated the growing sentiments against the government and in favor of individual rights among the citizens by decreasing the influence of politicians from 28.50 to 18.9%, and increasing the influence for the Hemlock Society by nine percentage points. Consequently, assisted suicide won by a very slight margin. We found this to be strongly supported by the situation in Oregon, where the bill legalizing assisted suicide was passed by a 51–49% vote.

Citizens in the South are very religious and are more conservative than the rest of the population. Therefore, we increased the percentage for the religious groups from 6.50 to 23.9%, This confirmed our initial results in that the status quo received a higher ratio then assisted suicide and active euthanasia. The major difference is that people in the south consider assisted suicide to be worse than active euthanasia.

Fig. 16.10 Religious groups' costs hierarchy



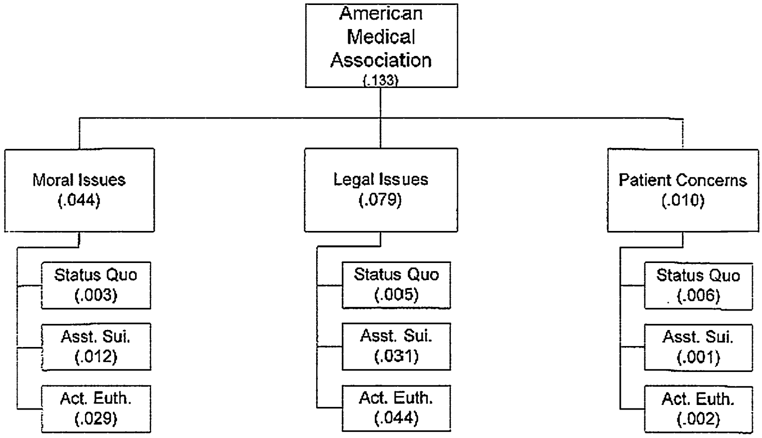


Fig. 16.11 AMA's costs hierarchy

Table 16.1 Priorities and B/C ratios of the alternatives

	Politicians	General Population	Religious Groups	AMA	Hemlock Society		
	0.285	0.484	0.066	0.133	0.032		
Benefits						TOTAL	B/C Ratio
Status Quo	0.055	0.095	0.053	0.035	0.002	0.240	1.404
Assisted Suicide	0.156	0.234	0.008	0.067	0.008	0.473	1.318
Active Euthanasia	0.074	0.155	0.005	0.031	0.022	0.287	0.611
Costs						TOTAL	
Status Quo	0.055	0.085	0.003	0.014	0.014	0.171	
Assisted Suicide	0.088	0.196	0.024	0.044	0.007	0.359	
Active Euthanasia	0.142	0.203	0.039	0.075	0.011	0.470	

Table 16.2 Priorities for the west

West	Benefits	Costs	B/C Ratio
Status Quo	0.232	0.196	1.184
Assisted suicide	0.451	0.350	1.289
Active Euthanasia	0.317	0.454	0.698

Table 16.3 Priorities for the south

South	Benefits	Costs	B/C Ratio
Status Quo	0.348	0.151	2.305
Assisted suicide	0.412	0.357	1.154
Active Euthanasia	0.329	0.491	0.670

Table 16.4 Priorities for pittsburgh

Pittsburgh	Benefits	Costs	B/C Ratio
Status Quo	0.314	0.155	1.184
Assisted suicide	0.437	0.356	1.228
Active Euthanasia	0.249	0.489	0.509

Pittsburgh has a large catholic population and is renowned for its medical facilities. As a result, we increased the religious factor to 17% and increased the AMA's influence to 17% as well. This led to a final decision to keep the status quo by a large margin. This is not too surprising seeing that the religious groups are categorically against assisted suicide and active euthanasia.

In all three cases, active euthanasia was never a consideration because most citizens, regardless of geographic location, do not look favorably on a physician taking life instead of sustaining it.

16.5 Conclusions

The analysis done using the AHP, suggests that the *Status Quo* should be maintained. The *Status Quo* states that if a patient requests to discontinue medical services, then a doctor must abide by his or her wishes. The sensitivity analysis confirmed this decision except in the West, where legalization of euthanasia has advanced much further than any other region. The end results confirm a conservative trend which has been sweeping the country, and also indicates people's unwillingness to take life into their own hands. The issue of assisted suicide and euthanasia will not be resolved overnight, and will continue to divide people along geographic, racial, and ethical lines.

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Chapter 17
How Should Congress Address the Medicare Crisis?

17.1 Introduction

The Medicare program was initiated in 1965 when the federal Social Security Act of 1965 was passed. Title 18 of this act established a two section provision for the Medicare program. Part A, which provides health benefits to its beneficiaries, protects them against hospital related costs. This provision is financed through a 2.9% Social Security payroll tax. Part B provides supplemental medical insurance benefits to protect enrollees against the costs of physician services, supplies, tests and some home health services. This provision is financed through voluntary premiums and matched by funds from general revenues.

Medicare has been, perhaps, the most successful of America's social programs. Almost all Americans sixty-five and older obtain health insurance through the Medicare program. In order to keep this program successful, it has been modified nine times through provisions such as the Social Security Act of 1972, which established Professional Standards Review Organizations to monitor necessity and quality of services, and the Omnibus Budget Reconciliation Act which removed co-payments for Part B services and limits on home health care visitations.

While Medicare has been a success to the approximately 47.7 million people to whom it directly provides service, it also has an impact on health care providers. In Pennsylvania, Medicare revenues account for about 57% of total hospital days. Additionally, some rural hospitals in Central Pennsylvania have an even greater dependence on Medicare funds. Lastly, Medicare provides almost all the revenue received by home health agencies, hospices and renal dialysis facilities. For these reasons, Medicare is far more important to the health care industry as a whole than to the elderly alone. Due to the number of people who are impacted by the Medicare program, Congress faces a difficult political and public issue. The reason that Congress must address this issue is because the Medicare trust fund, which reimburses providers for services delivered to Medicare recipients, is being depleted on a daily basis.

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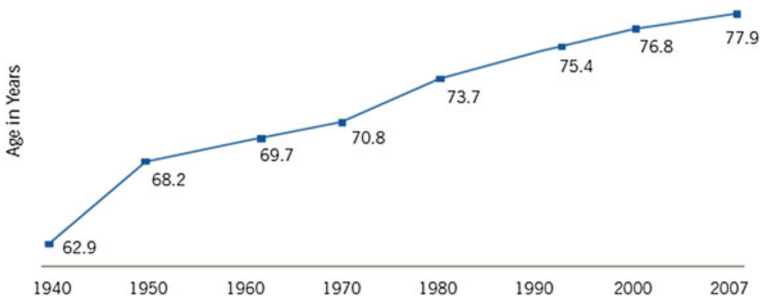

Fig. 17.1 U.S. life expectancy at birth 1940–2007. Source: National Center for Health Statistics (2010) Deaths: Final Data for 2007. Hyattsville MD. Access at http://www.cdc.gov/NCHS/data/nvsr/nvsr58/nvsr58_19.pdf

The ability of Medicare to remain successful is currently being tested. The main reason for this crisis is that Medicare expenses are expected to rise more rapidly than the revenue generated by payroll taxes. The reason for these increases is the combination of the high cost of health care and an increasingly aged population. In addition to the increase in age of our population, the elderly population has an increasing life expectancy (see Fig. 17.1).

Currently, the eighty five and over age group is the fastest growing aspect of the population in the United States. To make matters worse for Medicare financing, this group also consumes the most medical care per capita.

According to the "2010 Annual Report of the Boards of Trustees of the Federal Hospital Insurance and Federal Supplementary Medical Insurance Trust Funds" the Medicare Trustees are required to test annually whether general revenues will finance 45% or more of total Medicare spending in any of the next 7 years. In 2010, for the fifth year in a row, the Trustees projected that general revenues will exceed 45% of total spending within a 7 year timeframe (in 2010), prompting them to issue a "Medicare funding warning." However, general revenue is projected to fall below the 45% level in 2011 and not reach that level again until 2022 (see Fig. 17.2).

The number of Medicare beneficiaries is expected to increase. In addition, the baby boomers will begin to tremendously increase the number of Medicare enrollees in the year 2010. The problem of providing coverage for this increase in enrollees is compounded by legislative initiatives to reduce the federal financing of Medicare (see Fig. 17.3).

Given this increase in membership and reduction in funding, a crisis is on the horizon for the Medicare program. According to projections by the Kaiser Family Foundation based on data from the 2009 and 2010 Annual Report of the Boards of Trustees of the Federal Hospital Insurance and Federal Supplementary Medical Insurance Trust Funds, the Part A Trust Fund is projected to be depleted by 2029. This is largely due to reductions in the growth rate of Medicare spending as a result of provisions in the 2010 health care reform law, as well as a provision to increase the payroll tax paid by higher-income people. As a result, the Part A Trust Fund is projected to have a positive asset balance of $317 billion at the end of 2019 (see Fig. 17.4).

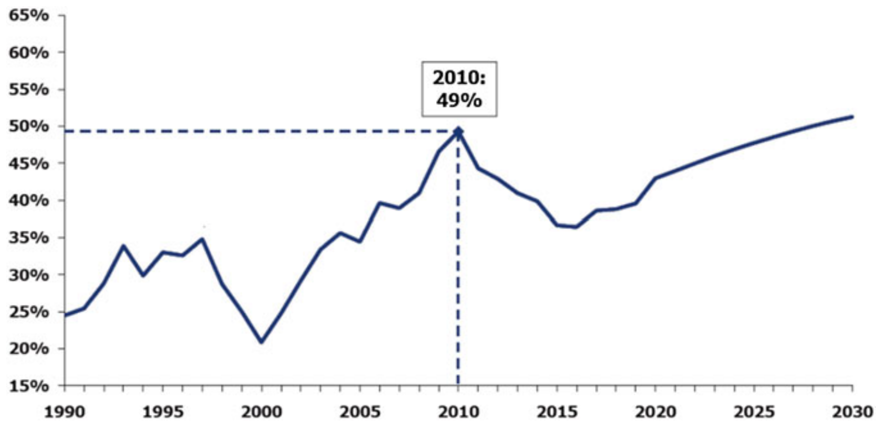

Fig. 17.2 General revenue as a percent of medicare spending 1990–2030

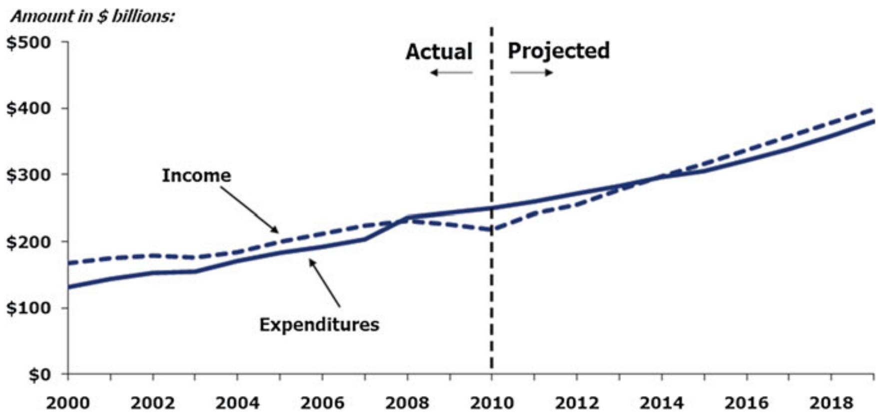

Fig. 17.3 Income and expenditures of the medicare part A trust fund

Because this issue continues to cause political uproars from the health care industry and political action committees such as the American Association of Retired People, legislative action will be required to resolve this issue.

17.2 The Analytic Hierarchy Model

Before we used the AHP decision making model we conducted research and utilized our own knowledge of the health care industry to generate potential alternatives which Congress could utilize in resolving the dilemma facing Medicare. During this process, we generated eight possible alternatives. They are:

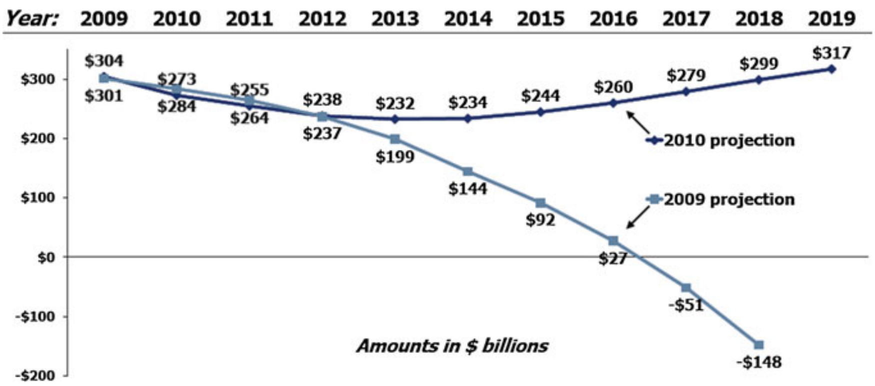

Fig. 17.4 2009 and 2010 projections of the medicare part A trust fund balance

1. Enact a Medicare means testing requirement as a way to reduce the number of beneficiaries eligible to receive Medicare coverage.
2. Deny the problem and do nothing.
3. Institute a National Health Insurance program in which all Americans are covered by one insurance plan.
4. Force families to provide insurance for their elderly family members.
5. Discontinue federal funding of the program, thus dissolving Medicare.
6. Mandate managed care enrollment of all Medicare beneficiaries thus reducing total expenditures.
7. Increase the age requirement to be eligible for Medicare.
8. Increase the Medicare payroll tax.

Although we utilized these eight alternatives in our AHP analysis, the purpose of our model is that it can be used to evaluate the potential success of any option that Congress may consider. Any potential solution to the Medicare program's financial problems obviously will contain costs, benefits, risks, and opportunities. Because Medicare is a social policy, we felt that any resolution must be weighted most heavily on its benefits to society. For this reason, and we assigned benefits a weighed value of 0.467 based on its overall significance.

As we stated earlier in this paper, the Medicare program affects not only those enrolled in the program but also a huge number of Americans through the wage tax. When addressing a program that has an effect on so many people, the risk of a wrong decision is a major concern. We assigned a weighted value of 0.217 to be applied to given alternatives based on their overall risks. The risks rated most favorably are those in which we assessed the consequences to be the least severe.

Costs are another consideration. Since high expenditures were the issue which brought the Medicare crisis into the spotlight, an alternative's cost must be a factor. Although the Costs of an alternative are a vital component in decision making, we feel that the benefits of a public program and the risks involved with changing it outweighed many of the costs associated with a given alternative. Because of this, we prioritized costs with a weighted average of 0.160.

Although it seems counterintuitive, the opportunities which arise from potential alternatives carry the least amount of significance in our model. Currently, the Medicare program is in a crisis situation with its survival in question. Consequently, we do believe that the opportunities presented by an alternative are of major significance in its potential success. We assigned a weighted value of 0.095 due to our reasoning and the help of AHP.

17.3 Analysis of Benefits, Risks, Costs and Opportunities Components

Benefits (0.467): We formulated six different benefits of any potential legislative alternative. These benefits and their rankings were:

1. Coverage (0.382): Since Medicare is a social policy initiative which was conceived and designed to provide medical care coverage for the elderly, we felt that the most significant indicator of an alternatives benefits is the coverage of as many eligible people as possible.
2. No change (0.250): Due to the fact that Medicare enrollees are satisfied with the plan, and since the health care sector's providers are so dependent on it, we placed a significant amount of weight into not changing the structure of the system.
3. Transfer of Risk (0.160): A common trend in health care is to control costs by transferring risk to other organizations operating within the industry. This has proven effective in controlling cost and improving health. For this reason, we gave this trend a notable amount of weight in our decision making model.

We will only elaborate on the top three factors in each category. The final three benefits whose contributions are less significant in the overall picture are:

4. Reducing the total amount of dollars spent (0.101).
5. Promoting the free market principles of capitalism (0.064).
6. Reducing the total number of people enrolled in Medicare (0.043).

Opportunities (0.095): We have identified five potential opportunities which are relevant to most proposed alternatives. These five opportunities and their weights are:

1. Financial savings (0.419): With Medicare facing bankruptcy, cost saving initiatives are a major concern. Clearly, the chance to save a considerable amount of money is the most significant opportunity. Cost savings can occur as the result actions such as disbanding the program, converting the delivery of Medicare to managed care, reducing the number of Medicare beneficiaries, and reducing the number of covered services.
2. Manage Care (0.263): Managed care methodologies can provide a significant opportunity for case managers to aggressively manage the delivery of medical care to Medicare enrollees. Through preventative measures, these methods

provide an opportunity for enrollees to remain healthy and consume fewer medical services. These are favorable outcomes, and are weighted as such.

3. Private insurance industry growth (0.160): Alternatives which limit the number of people who are covered under Medicare insurance could lead to an increased demand for private health insurance. As such, when people are excluded from Medicare, the opportunity exists that they would subscribe to private plans, and therefore, boost the economy and improve the risk pool in private plans.

The remaining two opportunities are:

4. Remaining "status quo" and attempting to find ways to improve it (0.097).
5. Elimination of insurance company selection biases (0.062).

For the next two components, costs and risks, the weights assigned represent the reserve of the weights assigned to benefits and opportunities. Thus the greater the cost/risk of an alternative the snaller the weight assigned.

Costs (0.160): We derived seven potential costs which affect most alternatives to solving the Medicare crisis. The seven costs and their weights are:

1. National Debt (0.031): Increases in the national debt, through increases in Medicare expenditures, are highly undesirable. Since Medicare is a very costly program, and we want to control expenses, we assigned a very low weight to it.
2. Political (0.045): Legislators have realized the political costs of making a wrong decision concerning Medicare for many years. Now that Medicare reform is urgent, legislators will want to minimize their potential costs of any decision.
3. Inflation (0.068): Congress must attempt to keep the growth of this program parallel to the inflation rate. Currently, the increase in Medicare expenditures not only exceeds the rate of inflation, but it is increasing at a rate greater than that of general inflation. For this reason, cost reduction efforts are desirable.

The final four costs and their weights are:

4. Health status changes in the elderly (0.104).
5. Administrative costs associated with administering the program (0.159)
6. Problems with the reduction in access to medical care (0.240).
7. Economic welfare losses associated with changes in individual and government expenditures (0.354).

Risks (0.227): We generated five different possible risks for potential alternatives. Once again, please note that the biggest risks possess the smallest weights. These risks and their weights are:

1. Bankruptcy (0.062): The largest and most significant risk to the program is bankruptcy. Due to obvious health and industry issues, no one wants this program to dissolve because of a lack of available funds. Since the current level of Medicare expenditures already exceeded income in 2010 (see Fig. 17.3), we gave this factor significant weight.

2. Political (0.097): Medicare has many political risks for legislators. Due to the immense lobbying power of the American Association of Retired People, the American Medical Association and other interest groups affected by Medicare, legislators have taken a "hands-off" approach whenever the Medicare debate develops. The fear of losing votes during their next election is very real, so this risk carries notable weight.
3. Rationing of Services (0.160): If Medicare reimbursements continue to be reduced, the services of providers may need to be rationed among enrollees. The reduction of health care services to the elderly is a significant risk, and is present in most options. Rationing is generally viewed as unacceptable.

The final two risks and their weights were:

4. Increasing the total number of uninsured (0.263).
5. The achievement of significant dollar savings (0.419).

17.4 Ethical Considerations

Although ethical behavior was not one of the four basic categories used in evaluation, the topic does deserve mention. Regardless of the results AHP helps to derive, it would not be right for people who paid Medicare payroll taxes throughout their working careers to not receive the benefit of insurance coverage. A potential resolution to this issue would be that the Medicare payroll tax be structured and viewed as a type of insurance for medical care if people do not have the means to buy it themselves when they are old.

Based on their decisions, members of Congress face the threat of losing campaign donations. Legislators must try to be ethical in their decision making and not let this threat sway their judgment. Additionally, hidden agendas and bureaucracy must not take precedence over such a major issue. Legislators must work together for the betterment of our country and not the betterment of their career and political party.

17.5 Results

To rate the alternatives according to their benefits, opportunities, costs and risks, we first constructed rating scales given in Table 17.1. The description of each of the intensities in the scales is given in Table 17.2.

In Table 17.3 each of the alternatives is rated according to their benefit, opportunity, cost and risk level. Each of the intensities has a numerical value in Table 17.1. The resulting values are transformed into an ideal scale, i.e., each

Table 17.1 Benefits, opportunities, costs and risks rating scales

		Ideal	Weighted
Benefits	**0.467**		
Coverage	0.382	1.000	0.467
No change	0.250	0.654	0.305
Risk	0.160	0.419	0.196
Reduce $	0.100	0.263	0.123
Free Mkt	0.064	0.168	0.078
Members	0.043	0.112	0.052
Opportunities	**0.095**		
$ Saving	0.421	1.000	0.095
Manage	0.263	0.625	0.059
INS grow	0.158	0.375	0.036
System ok	0.095	0.225	0.021
No bias	0.063	0.150	0.014
Costs	**0.160**		
Economic	0.030	0.088	0.014
Access	0.046	0.132	0.021
Admin $	0.069	0.200	0.032
Health	0.102	0.294	0.047
Inflation	0.158	0.455	0.073
Political	0.248	0.714	0.114
Debt	0.347	1.000	0.160
Risks	**0.277**		
$ Saving	0.061	0.147	0.041
Uninsured	0.097	0.233	0.065
Rationing	0.161	0.386	0.107
Political	0.263	0.630	0.174
Bankrupt	0.417	1.000	0.277

Note that the weights corresponding to the costs and risks intensities are the reciprocal values normalized to unity of those given in Sect. 17.2

entry is divided by the largest value of the corresponding scale. The result is given in Table 17.4.

Next we computed the short term (BO/CR) and the long term (bB + oO – cC − rR) value of the alternatives, where

$$\mathrm{BO/CR} = (\mathrm{Benefits} * \mathrm{Opportunities/Costs} * \ \mathrm{Risks})$$

and

$$\mathrm{bB} + \mathrm{oO} - \mathrm{cC} - \mathrm{rR} = \mathrm{b} * \mathrm{Benefits} + \mathrm{o} * \mathrm{Opportunities} - \mathrm{c} * \mathrm{Costs} - \mathrm{r} * \mathrm{Risks},$$

where b, o, c and r are the weights of the benefits, opportunities, costs and risks, respectively.

Table 17.2 Description of the rating scales

	Description
Benefits	
Coverage	Universal health insurance coverage
No change	Maintain the program as is—status quo
Risk	Transfer risk from government to private firms
Reduce $	Decrease federal expenditures
Free Mkt	A market based, capitalistic scenario to health coverage
Members	Reduce the number of people covered in the program
Opportunities	
$ Saving	Achieve significant dollar savings
Manage	The health of subscribers would be aggresively managed
INS Grow	Private insurance would grow, enhancing the economy
System ok	Existing system gives good service and minimizes risk from change
No bias	Eliminates selection bias which results in poor risk pools
Costs	
Economic	Economic welfare loss
Access	Poor access and patient satisfaction
Admin $	Administrative costs of supporting the option
Health	Decrease in health status of the subscribers
Inflation	Continued inflation of Medicare expenses
Political	Political costs of selecting the option
Debt	Increase in national debt
Risks	
$ Saving	Achieve significant dollar savings
Uninsured	A higher number of uninsured people in the country
Rationing	Rationing of health care services
Political	Political costs of selecting the option
Bankrupt	The Medicare program can go bankrupt

Table 17.3 Rating the alternatives

	Benefits	Opportunities	Costs	Risks
Alternatives	0.467	0.095	0.16	0.277
Enact a Medicare means testing	Members	INS grow	Admin	Political
Deny the problem and do nothing	No change	System ok	Inflation	Bankrupt
Institute a national health insurance program	Coverage	No bias	Debt	Rationing
Force families to provide insurance	Reduce $	INS grow	Economic	Political
Discontinue federal funding	Free Mkt	$ Saving	Health	Uninsured
Mandate managed care	Risk	Manage	Access	$ Saving
Increase the age requirement	Members	$ Saving	Political	Uninsured
Increase the medical payroll tax	No change	System ok	Inflation	Political

Table 17.4 Numerical interpretation of the ratingsratings

	Benefits	Opportunities	Costs	Risks		
Alternatives	**0.467**	**0.095**	**0.160**	**0.277**	**BO/CR**	**bB + oO − cC − rR**
Enact a Medicare means testing	0.112	0.375	0.200	0.630	0.333	−0.119
Deny the problem and do nothing	0.654	0.225	0.455	1	0.324	−0.023
Institute a National Health Insurance program	**1**	**0.150**	**1**	**0.386**	0.388	**0.214**
Force families to provide insurance	0.263	0.375	0.088	0.630	1.783	−0.030
Discontinue federal funding	0.168	1	0.294	0.233	2.447	0.062
Mandate managed care	**0.419**	**0.625**	**0.132**	**0.147**	**13.580**	0.193
Increase the age requirement	0.112	1	0.714	0.233	0.672	−0.032
Increase the Medical payroll tax	0.654	0.225	0.455	0.630	0.514	0.079

17.6 Conclusions

We found the results to be very interesting. The AHP helped us to decide that in the short term Congress should mandate that all Medicare beneficiaries be enrolled into managed care health insurance plans. This result is favorable to us since the trend in health care is to change the financing and delivery of services from a treatment oriented system into a model of care management. This trend is especially evident in the Medicare market which is rapidly embracing the managed care methodology. Also, we are aware of the benefits of managed care and believe that this model can be effective.

Mandated Managed Care enrollment received very favorable weights in the AHP model due to the fact that this measure can transfer risks to other entities, achieve expenditure reductions, manage the care of beneficiaries and encounter only some of the problems with access. All of these components were very favorable in our analysis.

The surprise in our results was the long term alternative. We never imagined that the AHP would help us decide that instituting a National Health Insurance program would be a serious alternative. After reviewing our analysis, we realized the major reason this alternative came in second was that national health insurance provides universal health coverage to all individuals. The desire to have as many people covered as possible was the number one factor (carrying the most weight) of the number one component in our hierarchy. For this reason, this measure received a higher rating than we expected, although the negative aspects of national insurance, such as the high cost, kept it from being the top choice in the short term.

The costs, risks, benefits and opportunities were all ranked with the highest value being the most beneficial or detrimental. In analyzing the results on the attached spreadsheet, it is readily evident that mandating the use of Managed Care for all Medicare subscribers has the highest benefit to cost ratio (13.58 ratio). Although other alternatives had higher ratings of benefits and opportunities, the low cost and risk of managed care was the biggest factor in it being the recommended choice. Intuitively, this choice seems the most appropriate of the alternatives offered.

In the short term, there are two results which AHP presents that are surprising. First, AHP suggests that the second best option is for Congress to Discontinue Federal Funding of the Medicare program (2.45 ratio). This option is most undesirable because it would result in the end of the program (which we are trying to avoid) and millions of individuals having no health insurance coverage. The consequences of this, both from an economic and health standpoint, would be significant and disastrous. The second surprise was that an alternative we considered as potentially successful, Enacting Means Testing, was ranked as one of the least desirable options (0.33 ratio). This option was attractive to us because it would reduce the number of individuals on the Medicare program by removing those who have the means to obtain private insurance and continuing to serve those in the most need. Although we do not view this as the answer to the whole Medicare problem, it would be a step in the right direction. However, we saw the reduction of members and potential growth of private insurance as relatively small benefits and consequently assigned a low benefit and opportunity rating.

In the long term, Managed Care was second to a National Health Insurance Program. What make the National Health Insurance Program unattractive in the short term is the costs associated with it.

Clearly, the issue of the Medicare crisis has many factors which influence the course of action which Congress will take. Even if an exact answer to the problem is not obtained, the process of utilizing AHP will help clarify the issues and priorities pertinent to achieving resolution. With careful preparation, Congress would be well served through the use of the AHP in identifying and evaluating favorable options to consider.

Chapter 18
Ethics in International Business

18.1 Introduction

Ethics is the science of judging specifically human ends and the relationship of means to those ends [1, p. 2]. It is essentially the art of controlling means so that they will serve specifically human ends. Business ethics is concerned primarily with the relationship of business goals and techniques to specifically human ends. It studies the impact of acts on the good of the individual, the firm, the business community, and society as a whole. While it does not concentrate on the obligations which a person has as a private individual and a citizen, these enter in since the business person is all three of these people in one. This means that business ethics studies the special obligations which a person and a citizen accepts when he or she becomes a part of the business world. Today's business world is one of ever increasing competition where there is great pressure on businesses to maintain increasing growth rates and profit margins to continually drive the company/s stock price upward. As international competition has dramatically risen in recent years there has been unprecedented changes that have been forced upon the workforce and normal business operations.

As the Japanese and European Communities continue to expand their economic influence, the United States will be increasingly forced to operate internationally to maintain increasing profits from period to period (quarter to quarter). These practices tend to focus on short-term returns to limit any possibilities of a downward trend in the stock price of a manager/s specific company. As the importance of profitability in the short-run increases, pressure will be focused on management to behave in an unethical manner in order to compete favorably in the international arena.

Ethics have always been a key issue for businesses, but as international expansion continues, temptations will be prevalent to cut corners to achieve increasing profits. Many foreign countries legally permit unethical practices and foster a business environment where corruption runs rampant. For example,

T. L. Saaty and L. G. Vargas, *Models, Methods, Concepts & Applications of the Analytic Hierarchy Process*, International Series in Operations Research & Management Science 175,
DOI: 10.1007/978-1-4614-3597-6_18, © Springer Science+Business Media New York 2012

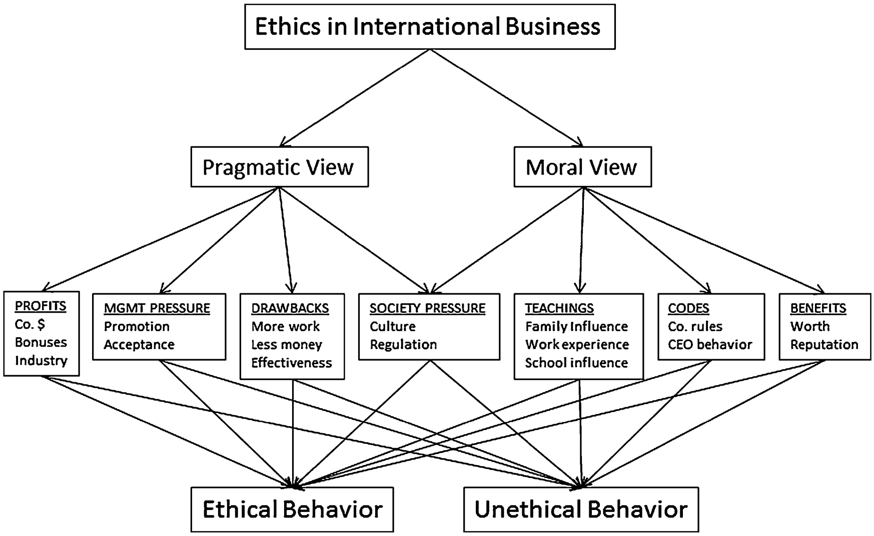

Fig. 18.1 Hierarchy of ethical/unethical behavior

Germany, U.K., and Denmark actually allow incentive payments and term them tax deductible business expenses [2, p. 80].

This AHP model helps to evaluate the choices the management of each company will have to make when operating in an international business environment in regards to ethical or unethical behavior (Fig. 18.1).

18.2 The Analytic Hierarchy Model

Even though every company will publicly admit to only ethical actions within their business, many companies behave in unethical manners behind closed doors. The model is based on the viewpoint of a manager within the ranks, and not the company in general. The first level of the hierarchy breaks down two types of views on the corporate world—the pragmatic and the moral points of view.

The pragmatic, or practical, viewpoint is the view of the manager who wants to meet his profit targets regardless of the actions involved or their implications. The moral, or ethical viewpoint, is the view of the manager who goes about achieving his or her goals within certain absolute limitations on behavior. The pragmatic viewpoint is split into four subcriteria; importance of profits, pressure from upper management to achieve profit goals, drawbacks of acting in an ethical manner, and society's norms and regulations. The moral viewpoint is also split into four criteria that include the ethical teachings of the past, the codes of conduct of the company, the benefits of acting ethically, and society's norms and regulations. The synthesis

Decision Goal: Ethics in International Business

- 0.5 **Pragmatic View**
  - 0.295 **Profits**
    - 0.191 **Co $**
    - 0.068 **Bonuses**
    - 0.036 **Industry**
  - 0.114 **Management Pressure**
    - 0.095 **Promotion**
    - 0.019 **Acceptance**
  - 0.032 **Drawbacks**
    - 0.011 **More work**
    - 0.011 **Less money**
    - 0.011 **Effectiveness**
  - 0.059 **Society Pragmatic Pressure**
    - 0.036 **Culture Pragmatic view**
    - 0.024 **Regulation Pragmatic view**
- 0.5 **Moral View**
  - 0.157 **Teachings**
    - 0.063 **Family Influence**
    - 0.063 **Work Experience**
    - 0.031 **School Influence**
  - 0.039 **Codes**
    - 0.024 **Company Rules**
    - 0.016 **CEO Behavior**
  - 0.069 **Benefits**
    - 0.041 **Worth**
    - 0.027 **Reputation**
  - 0.235 **Society Moral Pressure**
    - 0.129 **Culture Moral view**
    - 0.106 **Regulation Moral view**

Fig. 18.2 Priorities of the criteria

of these criteria with the judgments on priorities of each one will then result in the final choice of whether to behave ethically or unethically.

18.3 Model Application

Figure 18.2 shows the result of prioritizing the different components of the model in Fig. 18.1. According to this model 70% of the behavior can be attributed to Profits (Co. $—0.191; bonuses—0.068), Management Pressure (promotion—0.095), Societal Moral Pressure (culture—0.129; regulation—0.106) and Teachings (family influence—0.063; work experience—0.063).

In Table 18.1 the ethical/unethical behavior is evaluated in terms of the criteria. Note that unethical behavior seems to dominate 55/45. Were one to consider just the main criteria that capture 70% of the priorities we can see (Table 18.2) that unethical behavior is even more dominant 58/42.

Table 18.1 Ethical/Unethical priorities

Criteria		Ethical	Unethical
Co $	0.191	0.250	0.750
Bonuses	0.068	0.333	0.667
Industry	0.036	0.333	0.667
Promotion	0.095	0.333	0.667
Acceptance	0.019	0.333	0.667
More work	0.011	0.417	0.583
Less money	0.011	0.333	0.667
Effectiveness	0.011	0.333	0.667
Culture pragmatic view	0.036	0.500	0.500
Regulation pragmatic view	0.024	0.500	0.500
Family influence	0.063	0.667	0.333
Work experience	0.063	0.500	0.500
School influence	0.032	0.667	0.333
Company rules	0.024	0.545	0.455
CEO behavior	0.016	0.500	0.500
Worth	0.041	0.667	0.333
Reputation	0.027	0.667	0.333
Culture moral view	0.129	0.500	0.500
Regulation moral view	0.106	0.565	0.435
		0.447	0.553

Table 18.2 Ethical/Unethical priorities with most dominant criteria

Criteria		Ethical	Unethical
Co $	0.191	0.250	0.750
Bonuses	0.068	0.333	0.667
Industry	0.000	0.333	0.667
Promotion	0.095	0.333	0.667
Acceptance	0.000	0.333	0.667
More work	0.000	0.417	0.583
Less money	0.000	0.333	0.667
Effectiveness	0.000	0.333	0.667
Culture pragmatic view	0.000	0.500	0.500
Regulation pragmatic view	0.000	0.500	0.500
Family influence	0.063	0.667	0.333
Work experience	0.063	0.500	0.500
School influence	0.000	0.667	0.333
Company rules	0.000	0.545	0.455
CEO behavior	0.000	0.500	0.500
Worth	0.000	0.667	0.333
Reputation	0.000	0.667	0.333
Culture moral view	0.129	0.500	0.500
Regulation moral view	0.106	0.565	0.435
		0.419	0.581

18.4 Conclusions

The Analytic Hierarchy Process model suggests that there is a tendency to behave in an unethical manner when operating in an international business environment. By doing a sensitivity analysis, we concluded that the less pragmatic a manager becomes, the greater the chance is acting in an ethical manner. The results of this study show that, managers have a tendency to act in an unethical manner about 55% of the time, as compared to only operating in an ethical manner about 45% of the time. This may exemplify the decreasing values of today's society as short-term profits become the top priority of the corporate world. Society has never been, and will never be, completely ethical but it appears that as international competition increases the ethical standards of businesses are decreasing.

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Chapter 19
Abortion and the States: How will the Supreme Court Rule on the Upcoming Pennsylvania Abortion Issue?

19.1 Introduction

In the Summer of 1992 the Supreme Court of the United States was supposed to rule on a controversial Pennsylvania statute [10] restricting the rights of women in obtaining an abortion. Included in this statute are provisions requiring that doctors provide women with state-prescribed information about pregnancy and abortion, that the procedure be delayed 24 h after the recitation and that husbands be notified prior to the procedure. The lower court upheld the first two provisions but declared unconstitutional the husband notification requirement.

On January 22, 1973, the United States Supreme Court, in a landmark decision, ruled on the constitutionality of abortion by handing down judgments in two "test" cases: *Roe v. Wade* [12] and *Doe v. Bolton* [8]. The court replaced two states' statutes by declaring their restrictions on abortion unconstitutional. The court replaced the invalidated statutes with a uniform system clearly identifying the stages of pregnancy in trimesters and the "legal" enforcement one can expect during each trimester.

The Court used the "strict scrutiny" standard which applies to only a handful of constitutional rights that the Supreme Court has labeled "fundamental". They determined that the right to privacy, whether in the Fourteenth Amendment's definition of personal liberty, restricting government intrusion, or the Ninth Amendment's consignment of rights to the people, is broad enough to include the right to have an abortion. In denying a woman the choice of terminating an unwanted pregnancy, the state would create a hardship for the pregnant woman that could result in psychological harm [9, p. 11].

These rulings have come under close scrutiny since conservatives took office in 1980. Presidents Reagan and Bush have collectively appointed seven of the nine Supreme Court justices. Since the term of the president is four years and the term of a Supreme Court jurist is for life or until he or she voluntarily resigns, it is

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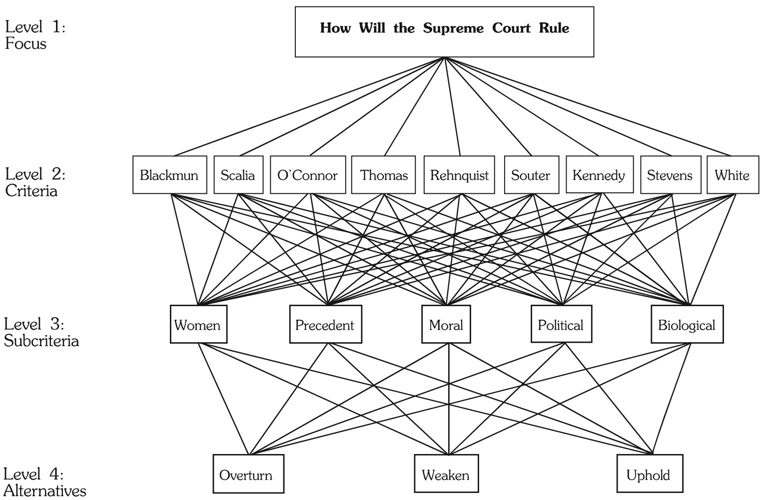

Fig. 19.1 Judicial decisions

possible for the political philosophy of an ex-president to have a profound effect on Court decisions for many years after he leaves office.

This chapter examines, with the assistance of the Analytic Hierarchy Process (AHP), how these justices might rule on the pending Pennsylvania statute limiting abortion rights. We used the nine Supreme court justices as our criteria, giving each of them an equal weight. Beneath each justice we used five subcriteria that we determined to be the most important. These criteria are: (1) Women's issues, (2) Precedent, (3) Moral issues, (4) Political issues and (5) Biological issues. These are individually outlined and defined below. Finally, we concluded that there were three likely outcomes of the ruling: overturn *Roe v. Wade*, uphold *Roe v. Wade* in its present form and weaken *Roe v. Wade* by giving states more independent power to restrict abortions. These, too, are outlined and defined below. Figure 19.1 shows the hierarchic representation used in this analysis.

19.2 Subcriteria

Women's issues: We defined women's issues as those issues deemed important by the Pro-Choice movement. This would include the constitutional right of each woman to make her own decisions regarding her body. Although we have defined this as women's issues, we do not claim that all women agree with the Pro-Choice movement nor that all men are Pro-Lifers.

Precedent: By precedent we mean the numerous cases that have gone before the Supreme Court since the early 1970s. Included in this, but not restricted to it, is Roe v. Wade. Also of importance are the cases of *Webster v. Reproductive Health*

Services which gave states more freedom to regulate abortions throughout the entire pregnancy, and *the City of Akron v. Akron Center for Reproductive Health* [5] which required parental consent, informed consent, a 24 h waiting period and the proper disposal of fetal remains.

Moral issues: We define moral issues as those issues deemed important by the Pro-Life movement. Included is the constitutional right of the fetus and the belief that abortion is murder and should be illegal.

Political issues: To make the decision-making process easier, we loosely defined political issues as conservatism. Although, not always true, we determined that conservatives are much more pro-life than liberals. Along the same vein we linked Republicans with conservatism and Democrats with liberalism.

Biological issues: Our broad definition of biological issues is *viability.* Viability is a medical concept that specifies a certain time within the gestation cycle when the fetus is capable of independent survival outside the mother's womb. This has been a difficult issue for the court to deal with because it is very closely related to the issue of "when life begins." In 1973, the court concluded [9, p. 1]:

> we need not resolve the difficult question of when life begins, when those trained in the respective fields of medicine, philosophy and theology are unable to arrive at any consensus. The judiciary, at this point in the development of man's knowledge, is not in a position to speculate as to the answer.

Also, in *Akron v. Akron Center for Reproductive Health* the Court ruled [5, p. 491]:

> A State may not adopt one theory of when life begins to justify its regulation of abortion.

The Court has thus far ruled that viability should be determined by the attending physician. The current problem is that modern medicine has allowed for much earlier viability than existed in 1973. Current medicine has allowed pre-third trimester fetuses to survive outside the womb. This is an issue which has not yet, but will likely, be dealt with by the courts.

19.3 Alternatives

We chose three alternatives that we felt were most likely to occur in the June ruling. In the past, including the very important case of *Webster v. Reproductive Health Services*, the Court has been averse to upholding or overruling *Roe v. Wade*. Whether or not this will be the case in the Pennsylvania ruling can only be determined by the Court.

First, we defined OVERTURN as disallowing abortion as a legal right in the United States. The court would rule that the right to an abortion is no longer a fundamental right protected by the Constitution. Basically, abortion would be legal only when the mother's life is in danger.

Second, we defined UPHOLD as allowing abortion to remain legal, without undue restrictions, in every state in the country. Basically, this would mean returning to the post-*Roe* era when there were no statutes limiting a woman's right to an abortion.

Finally, we defined WEAKEN as what is currently occurring in the United States with regard to abortion rights. Generally, this means granting individual states more power in controlling when and how an abortion can be received and who can receive it.

19.4 Criteria

As stated previously, we used as our criteria the nine justices currently sitting on the Supreme Court. Since each justice is allowed one "vote," we gave each equal weight. We used many experts' opinions from books and law journals to determine how each justice will weight each criterion and how each subcriterion will affect the alternative selected. Below we have outlined the major reasons for determining how each justice will vote:

William Rehnquist: As the most influential of the nine justices, Rehnquist's opinion is very important. Prior to his appointment as Chief Justice by President Reagan, Rehnquist ruled on many abortion cases as a regular jurist. He was one of two dissenting jurists in the *Roe v. Wade* decision. For this reason, we decided that PRECEDENT was not held in high regard by Justice Rehnquist, but that he would give it some weight (0.134) because of the recent cases limiting rights in which he concurred. We determined Rehnquist to be a conservative, and, therefore, we assumed that he would rank POLITICAL ISSUES about the same as precedent (0.118). In the area of WOMEN'S ISSUES we assumed that he would assign it a very low ranking (0.055); in fact, we ranked it lower than any of the criteria based on his ruling in *Roe v. Wade*. He opined [9, p. 15]:

> The fact that a majority of states have had restrictions on abortions for at least a century is a strong indication that the asserted right to an abortion is not so rooted in traditions and conscience of our people as to be ranked fundamental. Even today, when society's views are changing on abortion, the very existence of debates on the issue is evidence that the right to an abortion is not so universally accepted as one would have us believe.

In the area of BIOLOGICAL ISSUES, we thought that he would rank it low (0.086) because of *Webster v. Reproductive Health Services* in which he ruled that legislative determinations of when life begins are not per se unconstitutional. He ruled, in essence, that the Court permits a state to determine when life begins, but maintained that such determinations are not enough to save a statute if it is unconstitutional for other reasons [4, p. 513]. Finally, we determined that Rehnquist would weight the area of MORAL ISSUES very high (0.608) based on his earlier rulings, his belief that the right to an abortion is not a fundamental individual right, and his belief that fetuses should have individual rights.

Byron White: In most cases which we have researched related to abortion rights, Justice White has ruled very closely with Justice Rehnquist. For this reason, and because of his written opinions, we have ranked White very closely with Rehnquist. In the area of WOMEN'S ISSUES, we ranked White slightly lower than Rehnquist (0.045). And we weighted MORAL ISSUES very high (0.529). These criteria were ranked based on his opinion in the *Doe v. Bolton* case [9, p. 28]:

> In a sensitive area such as this, involving as it does issues over which reasonable men may easily and heatedly differ, I cannot accept the Court's exercise of its clear power of choice by interposing a constitutional barrier to states efforts to protect human life and by investing mothers and doctors with the constitutionally protected right to exterminate it.

For the PRECEDENT criterion, we gave it a low ranking (0.097) for the same reason we did with Rehnquist: because he dissented in *Roe v. Wade*. For POLITICAL ISSUES, we rated it low (0.091) because, although he has voted conservative, he was appointed by a Democratic President. Finally, for BIOLOGICAL ISSUES, we gave it a fairly high ranking (0.237) because of his belief that life begins at conception and, therefore, fetuses have rights that should be protected.

Antonin Scalia: Although we have very little information on how Justice Scalia would vote in an abortion case, his extremely conservative rulings in matters such as law enforcement and capital punishment led us to believe that he would vote accordingly on abortion. For this reason, and because he was appointed by President Reagan whose views on abortion are well-known, we gave him a high ranking on POLITICAL ISSUES (0.230). Also, because he has been critical of earlier rulings, namely *Roe v. Wade*, we ranked PRECEDENT low (0.089) and WOMEN'S ISSUES low (0.058). For BIOLOGICAL, we ranked it low (0.058) because we had little expert information. Finally, we ranked MORAL ISSUES high (0.565) because of his concurring viewpoint in *Webster v. Reproductive Health Services*: He never directly ruled on the issue of abortion, but made clear that he did not believe in the constitutional right of a woman to have an abortion. This led us to conclude that he believed in fetal rights and, therefore, moral issues should be ranked high.

Clarence Thomas: Because Justice Thomas was just recently appointed, we had no clear abortion rulings to use in our analysis. However, we do know that he has ruled very closely with Justice Scalia in almost all cases. In the Wall Street Journal it is stated that "…Justice Thomas continues to solidify his alliance with Justice Scalia. Not only do they nearly always vote on the same side of a case, but Justice Thomas's reasoning distinctly resembles that of Justice Scalia" [3, p. B6]. for this reason, we ranked each criterion identical to the rankings for Scalia: WOMEN'S ISSUES (0.058), PRECEDENT (0.089), MORAL (0.565), POLITICAL (0.230) and BIOLOGICAL (0.058).

John Paul Stevens: From our research, we found Stevens to hold individual rights and previous cases in high regard. Therefore, we gave PRECEDENT a high ranking (0.455). In a ruling in 1980, concerning state funding of abortions Stevens dissented with the majority seeing a "clear conflict with the decision in *Roe v. Wade*, which gave women the right to choose not to bear children. Here, government stacks the deck against this choice, at least for indigent women" [11, p. 160]. Also, this ruling established his beliefs in women's individual freedom to choose, and, as a result, we also ranked WOMEN'S ISSUES high (0.220). Because these beliefs directly conflict with our definition of MORAL ISSUES we ranked it low (0.054). We also ranked political very low (0.049) since he is not considered to be a conservative jurist. Finally, we ranked biological high (0.223) because of his concurring with the trimester system of determining when, and if, women can have an abortion.

Sandra Day O'Connor: Although, Justice O'Connor has been on the court for many years, it is unclear how she would rule in an abortion case. She has ruled in a few cases involving abortion but has not clearly stated her opinion. We know, however, that Justice O'Connor does not believe abortion to be a fundamental right deserving "strict scrutiny." Instead she uses the "undue burden" standard saying that laws should not burden "unduly" a woman's right to choose an abortion. Therefore, our research has led us to believe that Justice O'Connor will vote to restrict women's rights by strengthening the rights of the states, but will not vote to overrule *Roe v. Wade*.

We ranked the issues that we deemed will weaken *Roe* high, including PRECEDENT (0.397) and BIOLOGICAL (0.397) and the other criteria low; including, WOMEN'S ISSUES (0.110), MORAL (0.048) and POLITICAL (0.048). In his book, Dan Drucker states [9, p. 164]:

> O'Connor, the only woman to sit on the Court, can be expected to play a crucial role in its deliberations. O'Connor is in the middle; she supports the right to abortion, but she may be willing to restrict it in some way.

David Souter: Because David Souter was appointed recently, we had very little expert information to incorporate into our model. We found, however, many people believing him to be a "fair and thoughtful jurist" who bases his rulings heavily on prior cases. For this reason, we ranked PRECEDENT extremely high (0.640). We also found him to have a high regard for individual rights and used this information to rank WOMEN'S ISSUES high (0.125). We had little information on his moral beliefs or his feelings related to viability, therefore, we ranked MORAL ISSUES low (0.069) and BIOLOGICAL ISSUES low (0.068). Finally, although he was appointed by President Bush and should be politically conservative his disparate rulings in numerous cases involving issues of individual freedoms caused us to rank POLITICAL ISSUES fairly low (0.098).

Anthony Kennedy: Anthony Kennedy is also a new justice who has no record regarding how he will rule on abortion issues. Because he was appointed by President Reagan and considered extremely conservative by many, we ranked POLITICAL ISSUES high (0.179). Also, he is known to follow closely prior rulings and, therefore, we ranked PRECEDENT very high (0.590). For WOMEN'S ISSUES we used a very low ranking (0.065) based on a statement by Eve Paul, general counsel for Planned Parenthood which stated [9, p. 164]:

> This is a new Court. Kennedy is new and has not previously expressed his views on the abortion issue.

Table 19.1 Criteria weights for each judge

	Women	Precedent	Moral	Political	Biological
Blackmun	0.477	0.292	0.052	0.054	0.125
Kennedy	0.065	0.590	0.055	0.179	0.112
O'Connor	0.110	0.397	0.048	0.048	0.397
Rehnquist	0.055	0.134	0.608	0.118	0.086
Scalia	0.058	0.089	0.565	0.230	0.058
Souter	0.125	0.640	0.069	0.098	0.068
Stevens	0.220	0.455	0.054	0.049	0.223
Thomas	0.058	0.089	0.565	0.230	0.058
White	0.045	0.097	0.529	0.091	0.237

Regarding the remaining criteria, we ranked each quite low because of the lack of available information. For MORAL ISSUES we gave it a ranking of 0.055 and for BIOLOGICAL ISSUES we ranked it 0.112.

Harry Blackmun: Justice Blackmun is the only justice that we believe will definitely rule in favor of upholding a woman's right to have an abortion. He concurred in the *Roe v. Wade* decision and has voted to uphold it in every decision since. He made it clear that a woman's right to receive an abortion should not be weakened in his *Webster v. Reproductive Health Services* decision [9, p. 180]:

> Although today, no less than yesterday, the Constitution and the decisions of this Court prohibit a state from enacting laws that inhibit women from the meaningful exercise of that right, a plurality of this Court implicitly invites every state legislature to enact more and more restrictive abortion regulation in order to provoke more and more test cases, in the hope that sometime down the line, the court will return the law of procreative freedom to the severe limitations that generally prevailed in this country before January 22, 1973.

In fact, Justice Blackmun is very clear that the fundamental constitutional right of women to decide whether to terminate a pregnancy survives. He opined [9, p. 161]:

> I fear for the future. I fear for the liberty and equality of the millions of women who have lived and come of age in the 16 years since *Roe* was decided. I fear for the integrity of, and the public esteem for, this Court.

For obvious reasons, we ranked his criteria high that would uphold *Roe v. Wade* in its 1973 form. We ranked WOMEN'S ISSUES high (0.477), PRECEDENT high (0.292) and BIOLOGICAL ISSUES high (0.125). The criteria that would overturn or severely weaken *Roe v. Wade* we ranked low; MORAL ISSUES at 0.0252 and POLITICAL ISSUES at 0.054.

The priorities of the issues with respect to the judges are given in Table 19.1.

Next, we prioritized the alternatives with respect to each judge and each criterion. Table 19.2 summarizes the global priorities we obtained. The priorities of the alternatives are obtained by adding their weights (Table 19.2) for all the criteria and all the judges. We have: **Overturn (0.376), Weaken (0.399) and Uphold (0.225).** *It is our belief, based on the AHP model, that the Supreme Court will*

Table 19.2 Priorities of the alternatives for each judge

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Women									
(A)	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000
(B)	0.010	0.001	0.002	0.001	0.001	0.003	0.005	0.001	0.001
(C)	**0.042**	0.006	0.010	0.005	0.005	0.011	0.020	0.005	0.004
Precedent									
(A)	0.001	0.001	0.000	0.000	0.001	0.001	0.000	0.001	0.000
(B)	**0.023**	**0.046**	0.031	0.005	0.007	**0.050**	**0.035**	0.007	0.008
(C)	0.009	0.019	0.013	0.004	0.003	0.021	0.015	0.003	0.003
Moral									
(A)	0.004	0.005	0.005	**0.061**	**0.057**	0.007	0.005	**0.057**	**0.053**
(B)	0.001	0.001	0.000	0.006	0.006	0.001	0.001	0.006	0.005
(C)	0.001	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.001
Political									
(A)	0.005	0.016	0.004	**0.010**	**0.020**	0.009	0.004	**0.020**	0.008
(B)	0.001	0.003	0.001	0.002	0.004	0.002	0.001	0.004	0.002
(C)	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.000
Biological									
(A)	0.002	0.002	0.006	0.001	0.001	0.001	0.003	0.001	0.003
(B)	**0.010**	0.009	**0.033**	0.007	0.001	0.006	0.019	0.005	**0.020**
(C)	0.000	0.000	0.006	0.001	0.005	0.001	0.003	0.001	0.003

(1) Blackmun, (2) Kennedy, (3) O'Connor, (4) Rehnquist, (5) Scalia, (6) Souter, (7) Stevens, (8) Thomas, (9) White
(A) Overturn, (B) Weaken, (C) Uphold
The bold priorities represent the most likely standing of each justice in each issue

uphold at least parts of the Pennsylvania statue and will, as a result, weaken the rights of women who choose to have an abortion in the state of Pennsylvania.

On June 30 1992, The United States Law Week [13, p. 1,201] reported the result of the U.S. Supreme decision:

> The U.S. Supreme Court yesterday reaffirmed the core principles of Roe v. Wade, 410 U.S. 113 (1973), but at the same time upheld most of a restrictive Pennsylvania abortion statute. Only a provision requiring a woman to notify her husband before obtaining an abortion was struck down. *(Planned Parenthood of Southeastern Pennsylvania v. Casey*, US SupCt, Nos. 91-744 & 91-902, 6/2/92)

19.5 Conclusions

As shown in a recent poll conducted by Parade Magazine, abortion rights is a hot topic in the United States, one which is subject to fierce debate between Pro-choice advocates and Pro-lifers. Of the 2,538 people polled, 71% felt that abortion should remain legal and 61 percent believed Roe v. Wade should not be overturned [6, p. 4]. How the Supreme Court rules in June will certainly have a serious impact on the people of Pennsylvania, and most likely all citizens of the United States. This is a very complex problem without a clear cut solution. Certainly the type of problem suited for analysis by the Analytic Hierarchy Process.

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Chapter 20
The Benefits and Costs of Authorizing Riverboat Gambling

20.1 Introduction

On November 26, 1990, six months after the study on which this chapter is based was undertaken, the Pennsylvania House of Representatives rejected a bill to legalize riverboat gambling by a vote of 118-81.

Should riverboat gambling be permitted on Pennsylvania's rivers and lakes? What impact would this activity have on the state? What are the potential benefits? What are the possible costs? These are the questions that many are asking as a bill to authorized riverboat gambling is being considered by the Pennsylvania House of Representatives.

This chapter aims to determine the importance of the costs and benefits attributed to riverboat gambling and apply a sophisticated decision-making model to make a recommendation on the issue. First, the pending legislation is examined and the positions of those supporting and opposing the bill are delineated. Next, the Analytical Hierarchy Process (AHP) is applied to the riverboat gambling issue. Judgments acquired from individuals involved in the decision-making process or affected by the decision are then described. Finally, the synthesized results are interpreted, and a recommendation on riverboat gambling legislation is presented.

20.1.1 Pending Legislation on Riverboat Gambling

The Excursion Boat Gambling Bill, introduced by Representative Frank Gigliotti (D-Brookline), is expected to be brought up for vote in the House. It would authorize limited gambling on riverboats in Pennsylvania counties where the proposition is approved by voter referendum. The bill limits the maximum wager at $5 per hand or play and the maximum loss at $200 per person during each gambling excursion. The bill restricts gambling activity to 50% of a riverboat's square footage, requires gambling devices to pay out at least 80% of all wagers, and prohibits persons under 21 from engaging in gambling activities.

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DOI: 10.1007/978-1-4614-3597-6_20,

The Excursion Boat Gambling Commission, created under the bill, would license operators, adopt standards for the gambling operations, and regulate gambling activity. The commission would be funded through licensing and admissions fees. The initial license fee would be $50,000 with an annual fee of $25 per person-capacity on each riverboat. The admission fee, to be set by the EBG Commission, would be obtained for each person embarking on a riverboat gambling excursion. In addition, the municipality could adopt a local admission fee not to exceed 50 cents.

A wagering tax of 15% would be imposed on adjusted gross receipts from riverboat gambling. Twenty-five percent of the wagering tax would be distributed to each county having a home port or port of call, based on the ratio of the number of passengers embarking from that port to the total number of statewide embarkations. Another 25% would be allotted to the municipality, and the remaining amount would be credited to the General Fund of the state. Additionally, a recent amendment to the bill requires that $1,000,000 be allocated annually for the treatment of compulsive behaviors.

20.1.2 Positions of Supporting and Opposing Parties

Promoters of the bill claim [6], [7], [9] that riverboat gambling will stimulate local business, encourage economic development, and provide additional tax revenues for government. They cite examples of riverboat gambling operations in Mississippi, Iowa, and Illinois which have created new jobs and spawned tourism [8]. Supporters expect local economies to thrive as riverboat gambling patrons fill hotels, restaurants, and shops [2]. They also project that the legalized gambling operations will reduce illegal gambling [4], expand the tax base, and provide tax relief for citizens.

Opponents of the bill believe that legalization legitimizes gambling in the public mind and thus promotes gambling in both legal and illegal forms [1]. They expect serious social problems to result from an increase in the number of gamblers and compulsive gambling behavior [5]. They fear that riverboat gambling will lead to increased street crime, prostitution, and drug trafficking along with corruption, extortion, and bribery among public officials. Opponents claim that riverboat gambling will promote illegal gambling and attract organized crime to meet patrons' demands for credit betting, higher stakes, and avoidance of income taxes. It is also feared that legalized riverboat gambling will lead to pressures to allow gambling on Pennsylvania soil [3].

20.2 Problem Analysis

A team of three graduate students from the University of Pittsburgh applied the Analytical Hierarchy Process (AHP) to analyze Pennsylvania's pending legislation on riverboat gambling. A brief definition of the model and an explanation of the

Level 1: Goal	**Authorizing Riverboat Gambling in Allegheny County (benefits)**			
Level 2: Criteria	Economic	Political	Social	Environmental
Level 3: Decision Makers	State Government	Citizens	Lobbies	
Level 4: Factors	Social Opportunities	Economic Development	Revenue Gains	
Level 5: Groups Affected	Riverboat Operators	Citizens of Pittsburgh	Local Business	Government
Level 6: Objectives	-Increase Revenue -Diversification of Services	-Variety of Entertainment -Potential Tax Relief -Increase Job Opportunities	-Development Opportunities & Increase Employment -Increase Tourism -Provide National Recognition	-Increase Tax Revenues -Reduce Illegal Gambling -Improve Image of Pgh & PA
Level 7: Alternatives		**AUTHORIZE**	**NOT AUTHORIZE**	

Fig. 20.1 Benefits hierarchy

application are followed by a description of the judgments obtained from persons involved with the riverboat gambling issue (either as decision-makers or affected parties).

The goal of the model is to determine whether or not riverboat gambling should be authorized in Allegheny County. While the legislation encompasses the entire state of Pennsylvania, a more focused approach limited to Allegheny County provides more detail due to the team's familiarity with the area. Notably, the process can be applied to other local areas in Pennsylvania. Two similar hierarchies have been constructed, one identifying the benefits of the legislation (see Fig. 20.1) and the other identifying the costs (see Fig. 20.2). There are seven levels in each hierarchy identifying the goal, decision criteria, decision makers, factors, groups affected, objectives or issues, and alternatives.

Judgments obtained from decision makers and the groups affected were used to assign values of importance to the factors and objectives/issues. Those individuals in favor of the legislation were interviewed for the benefits hierarchy, and those against the legislation were interviewed for the costs hierarchy. Additional judgments were made regarding the importance of the decision criteria, decision makers, groups affected, and alternatives with respect to prior levels in the hierarchy.

Level 1: Goal	**Authorizing Riverboat Gambling in Allegheny County (costs)**					
Level 2: Criteria	Economic	Political	Social	Environmental		
Level 3: Decision Makers	State Government	Citizens	Lobbies			
Level 4: Factors	Damage to Environment	Potential/ Selective Economic Loss	Social Problems	Regulation Difficulties and Costs		
Level 5: Groups Affected	Riverboat Operators	Citizens of Pittsburgh	Local Gambling Businesses	Government	Other River Users	Environ-mentalists
Level 6: - Issues	- Regulation of Gambling Activities -Competition For Gambling Operations	-Safety & Crime Issues -Increase Traffic & Crowds -Moral Addiction	-Cannibalism of Other Legal Gambling Operations -Cannibalism of PA State Lottery -Govt Services - Law Enforcement & Waste Services	- Regulation of Gambling Operations	- Increase River & Need For Safety	-Increase Pollution
Level 7: **Alternatives**	**AUTHORIZE**	**NOT AUTHORIZE**				

Fig. 20.2 Costs hierarchy

20.2.1 Judgement of Decision-Makers

The relevant decision-makers in the model include the Pennsylvania State Government, voting citizens of Pennsylvania, and interest groups and lobbies. Telephone interviews were conducted in order to determine the importance of the primary cost and benefit factors with respect to their positive or negative influence on these decision-makers.

The three benefit factors in level 4 include:

- social opportunities (standard of living and variety of entertainment)
- economic development (employment and new business opportunities)
- revenue gain (for local businesses and the government)

The four cost factors in level 4 include:

- potential damage to the environment (pollution)
- potential/selective economic loss of individuals
- social problems (crime, corruption, and safety)
- regulation costs

20.2.1.1 State Government

As a decision maker, State Representative Gigliotti feels that economic development and revenue gains are the most important factors influencing his decision to support the bill. He believes that the gambling activities would promote a new variety of entertainment for the area, thus creating additional economic development opportunities [9].

State Representative Clymer [1] strongly opposes the Excursion Boat Gambling Act. He believes that potential economic loss to individuals and social problems are the most important factors. He stated that gambling does not create any new wealth, rather, it only redistributes the wealth. By providing more access to gambling, Representative Clymer feels that riverboat gambling would create new gamblers and even lead to more illegal gambling. He also thinks that regulation would be an important factor to prevent private games from being held for "high rollers."

20.2.1.2 Citizen of Pittsburgh

An unbiased citizen, who is completing his PhD in Public Affairs, rated increased social opportunities as the most important benefit and safety/crime issues as the most important cost impacting his decision on the legislation.

20.2.1.3 Lobbies/Interest Groups

A local representative for a community organization, who is interested in preserving Pittsburgh's standard of living through economic development and increased employment, feels that the riverboat legislation will provide Pittsburgh with economic advantages which will benefit the whole city and the surrounding neighborhoods. Consequently, this individual rated economic development as the most highly rated factor, followed by revenue gains.

A representative from a local pro-family organization, who does not support the current legislation, is primarily concerned about social problems and potential financial loss to individuals that may result if riverboat gambling is legalized.

20.2.2 Judgement of Groups Affected

In addition to talking with the relevant decision-makers, the groups which would be impacted by the legislation were interviewed about the respective issues and objectives in level 6 of the hierarchies. The following groups were identified as having a stake in the outcome of the legislation: riverboat operators, citizens of Pittsburgh, local Pittsburgh businesses, state and local government, other river users, and environmentalists.

20.2.2.1 Riverboat Operator

The local riverboat operator that was interviewed is strongly in favor of the legislation. The following two benefits are equally important to him: increased revenue and diversification of services. In terms of negative issues, he feels that increased costs of regulation are extremely more important than competition because regulation is not something that his operation has any control over.

20.2.2.2 Citizen of Pittsburgh

The citizen of Pittsburgh, who is completing his PhD in Public Affairs, feels that an increase in the number of jobs in the city is the most important benefit that could result from the passing of the current legislation. Possible tax relief for the taxpayers is secondary in importance to this individual. This particular citizen also thinks that the safety of the Pittsburgh residents may be jeopardized due to the potential for crime and corruption to increase in the city and surrounding areas.

20.2.2.3 Local Business

A representative from a large Pittsburgh hotel believes that the most important benefit that could result from the legislation is the potential for the number of tourists being drawn to the area to increase. He could not foresee any costs associated with riverboat gambling.

20.2.2.4 Local Gambling Business

The team was unable to obtain the cooperation of a large local gambling operation, likely to be impacted by this legislation. The assumption has been made that increased competition for local gambling dollars could result and affect existing gambling operations in a negative way.

20.2.2.5 State and Local Government

Representative Gigliotti envisioned the positive effects of increased tax revenues for local and state government to be the most important objective of having riverboat gambling in Pittsburgh and Pennsylvania. If the bill were to be passed, Representative Clymer felt that regulation would the most important issue for government. He said that he did not want to promote gambling, and he felt that the wagering and maximum loss limits would be increased in response to growing consumer demand.

20.2.2.6 Other River Users

The two barge companies that were interviewed felt that any increase in the number of boats to be used for riverboat gambling would have no effect on their current operations in terms of increased traffic on the Pittsburgh waterways.

20.2.2.7 Environmentalist

An interview with a representative from a local environmental group, who is concerned about having clean water and air, revealed that the legislation would not impact his organization significantly with respect to the issue of increased pollution.

The priorities derived from the judgments are given in Tables 20.1 and 20.2.

20.2.3 Additional Judgements

The decision criteria in level 2 of the hierarchies consist of economic, political, social, and environmental measures which were rated differently in the two hierarchies. In the benefit hierarchy, the economic criterion was rated most important, and in the cost hierarchy, the social criterion was considered most important. The political criterion was deemed more important in terms of costs than benefits. Environmental concerns were judged relatively unimportant in both hierarchies.

Since the bill requires passage in the state government and in individual counties by voter referendum, state government and citizens in level 3 of the hierarchies were rated equally important as decision-makers. The lobbies and special interest groups that influence the decisions were weighed with a lesser degree of importance.

Based on benefit and cost factors, the groups affected by riverboat gambling in level 5 of the hierarchies were weighted. Pittsburgh citizens were rated as the most important group affected by the social opportunities. Riverboat operators and local businesses were considered to be most affected by economic development and revenue gains. Government was also judged to be important in these areas. In terms of costs, Pittsburgh citizens and environmentalists were weighed heavily as groups affected by damage to the environment. The citizens of Pittsburgh were also considered to be most affected by potential economic loss and social problems. River boat operators and government were judged to be the most important groups affected by regulation costs.

The final set of judgments involved rating the two alternatives in level 7 in terms of each objective or issue. In the benefits hierarchy, the alternative to authorize riverboat gambling was weighted most heavily under increased tax revenues, diversification of services for riverboat operators, and variety of entertainment for citizens. In the costs hierarchy, the alternative to authorize riverboat

Table 20.1 Priorities of benefits

	Economic (0.658)	Political (0.085)	Social (0.218)	Environmental (0.040)
State Gov.	0.444	0.444	0.444	0.444
Citizens	0.444	0.444	0.444	0.444
Lobbies	0.111	0.111	0.111	0.111

	State gov	Citizens	Lobbies
Social opportunities	0.114	0.637	0.051
Economic development	0.481	0.258	0.367
Revenue gains	0.495	0.105	0.582

	Social opportunities	Economic development	Revenue gains
Riverboat operators	0.049	0.637	0.051
Citizens of Pittsburgh	0.551	0.258	0.367
Local business	0.104	0.541	0.376
Government	0.296	0.138	0.211

	Riverboat operators	Citizens of Pittsburgh	Local business	Govt.	Composite priorities
Increase revenue	0.5				0.115
Diversification of services	0.5				0.115
Variety of entertainment		0.114			0.024
Potential tax relief		0.405			0.087
Increas job opportunities		0.481			0.103
Dev. opport. increase empl.			0.113		0.039
Increase tourism			0.709		0.244
Provide national recognition			0.179		0.062
Increase tax revenues				0.773	0.165
Reduce illegal gambling				0.088	0.019
Improve image of Pgh and PA				0.139	0.030

Table 20.2 Priorities of costs

	Economic (0.045)	Political (0.260)	Social (0.611)	Environmental (0.084)
State Gov.	0.444	0.444	0.444	0.444
Citizens	0.444	0.444	0.444	0.444
Lobbies	0.111	0.111	0.111	0.111

	State government	Citizens	Lobbies
Damage to environment	0.037	0.058	0.045
Economic loss	0.313	0.102	0.296
Social problems	0.423	0.549	0.614
Regulations and costs	0.227	0.297	0.045

	Damage to environment	Potential/selective economic loss	Social problems	Regulation difficulties and costs
Riverboat operators	0.034	0.038	0.049	0.286
Citizens of Pittsburgh	0.305	0.496	0.405	0.132
Local business	0.030	0.038	0.049	0.042
Government	0.156	0.302	0.405	0.478
Other river users	0.100	0.056	0.047	0.032
Environmentalists	0.375	0.070	0.047	0.031

	Riverboat operators	Citizens of Pittsburgh	Local business	Government	Other river users	Environmentalists	Composite priorities
Regulation of gambling	0.5						0.054
Competition for gambling operations	0.5						0.054
Safety and crime		0.637					0.220
Increase traffic and crowds		0.105					0.036
Moral addiction		0.258					0.089
Cannibalism of other legal gambling			1				0.049
Regulation of gambling operations				0.600			0.227
Cannibalism of PA state lottery				0.200			0.076
Gov. law enforc./waste services				0.200			0.076
Inc. river traffic need for safety					1		0.053
Increase pollution						1	0.068

Table 20.3 Synthesized benefits and costs of riverboat gambling

Benefits	*Yes*	*No*	*Costs*	*Yes*	*No*
Tourism	0.85	0.15	Gov't reg.	0.90	0.10
Taxes	0.90	0.10	Safety	0.90	0.10
Revenue	0.85	0.15	Moral	0.95	0.05
Diverse	0.95	0.05	Lottery	0.90	0.10
Job opport.	0.85	0.15	Services	0.95	0.05
Tax relief	0.70	0.30	Pollution	0.50	0.50
Recognition	0.85	0.15	Regulation	1	0
Dev. opport.	0.85	0.15	Competition	1	0
Image	0.85	0.15	Inc. traffic	0.70	0.30
Variety	0.90	0.10	Cannibalism	0.85	0.15
Illegal	0.50	0.50	Traffic	0.85	0.15
Composite	0.851	0.149	Composite	0.877	0.123

gambling was considered most costly under moral addiction to gambling, government regulation, and government services.

20.3 Findings and Discussion

The weighted judgments were synthesized to quantify the importance of the hierarchical elements (Table 20.3). This process produced a benefit/cost ratio of 0.851/0.877 for authorizing riverboat gambling and a ratio of 0.149/0.123 for *not* authorizing riverboat gambling. These results indicate that riverboat gambling should *not* be authorized in Allegheny County. In evaluating the sensitivity of the priorities, it should be noted that a reduction in the importance of the two highest weighted cost issues would still yield the same alternative. Furthermore, an increase in the importance of the three highest weighted benefit objectives does not alter the decision.

In evaluating the validity of this AHP application, limitations must be recognized. The biases of the individuals interviewed and of the team members may slant the judgments thus affecting the results. Interdependencies or commonalities among elements in the hierarchy possibly existed but were minimized by constructing two separate hierarchies. Additionally, imperfect preferences may lead to inconsistencies among the elements in the model. However, a certain degree of inconsistency in making judgments is acceptable in real world applications.

USA Today reported January 7, 2010 that "Pennsylvania legalized poker, blackjack and other table games at slots casinos Thursday, upping the ante in the increasingly fierce competition among states for gamblers' money. Gov. Ed Rendell, whose signature was the last step in the protracted process of passing the law, said he had misgivings about expanded gambling, partly because not all of the 14 casinos authorized by the 2004 law that legalized slot machine gambling are up and running." It took almost ten years since it was proposed.

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Chapter 21
To Drill or Not to Drill: A Synthesis of Expert Judgments

21.1 Introduction

Petroleum exploration is a costly venture which always involves a great deal of uncertainties and unknown factors. A decision to drill could result in a giant discovery, a modest discovery, or a dry hole. The factors influencing drilling decisions could be of geologic, economic and personal nature. When making a decision based on geologic factors alone, geologists and geophysicists will try to find answers to the following questions [2].

1. Are there any hydrocarbons present in the geographical area under consideration?
2. If hydrocarbons are present, what are the chances of finding them?
3. What is the probable size of the reserves?

If the size of the reserves is known the concern includes how fast and at what cost could oil be produced. Most of these decisions must be made without adequate statistical data.

There are numerous methods of estimating oil and gas resources in a reservoir. Some of the more popular methods are Geologic Analogy [1], Delphi Technique [3], Areal Yield [3], and Volumetric Yield [6] in which the Monte Carlo method is used to simulate the probability distribution of the factors that determine the volume of hydrocarbon to be expected. Each method has its own advantages and limitations.

In this chapter we introduce a new approach which provides a framework for a systematic analysis of crucial geologic factors determining recoverable oil and estimating the probable size of the reserves.

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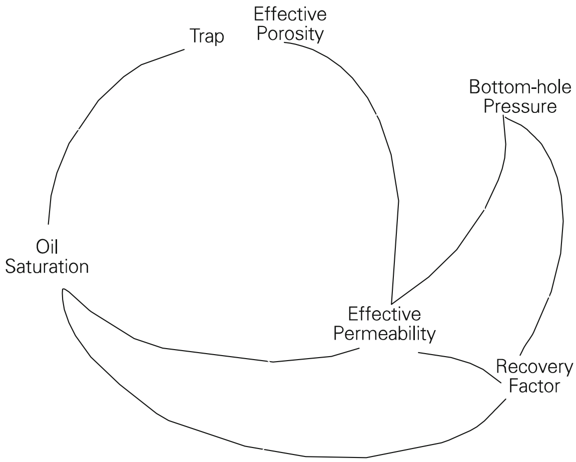

Fig. 21.1 Interrelationships of factors determining the quantity of recoverable oil in a reservoir

21.2 Model for Estimating the Volume of Recoverable Oil

The pre-condition for petroleum accumulation is the existence of a source rock, where oil and gas originate. Once formed, the oil and gas must migrate from the source rock into more porous and permeable rock called reservoir rock. The reservoir rock acts as a container for the fluids. A reservoir rock must have enough room to store a significant volume of hydrocarbons and must discharge oil or gas readily when the reservoir is penetrated by a well. In order to accumulate oil or gas, the reservoir rock must be deformed either by folding or faulting to form structural or stratigraphic traps.

In the structural type, the traps are the result of movements of the Earth's crust: folding, faulting, fracturing, or intrusion of a salt dome. A stratigraphic trap occurs when a porous rock layer is tilted and eroded. The eroded end is then sealed off by a tight rock layer. Also, to get the petroleum out, there must be some natural driving force within the reservoir, usually gas and/or water.

Figure 21.1 illustrates the interrelationships of the key factors determining the volume of recoverable oil in a reservoir and Fig. 21.2 is the hierarchy for estimating effective porosity (φ), oil saturation (S_o), effective permeability, recovery factor (RF), and bottom hole pressure (BHP). A brief explanation of each factor is given below.

21.2.1 Definitions of Geologic Terms

Petroleum trap: Petroleum trap is a geologic setting conducive to concentration and preservation of hydrocarbon. Petroleum traps are generally classified as structural and stratigraphic traps. A structural trap is a geologic setting resulting

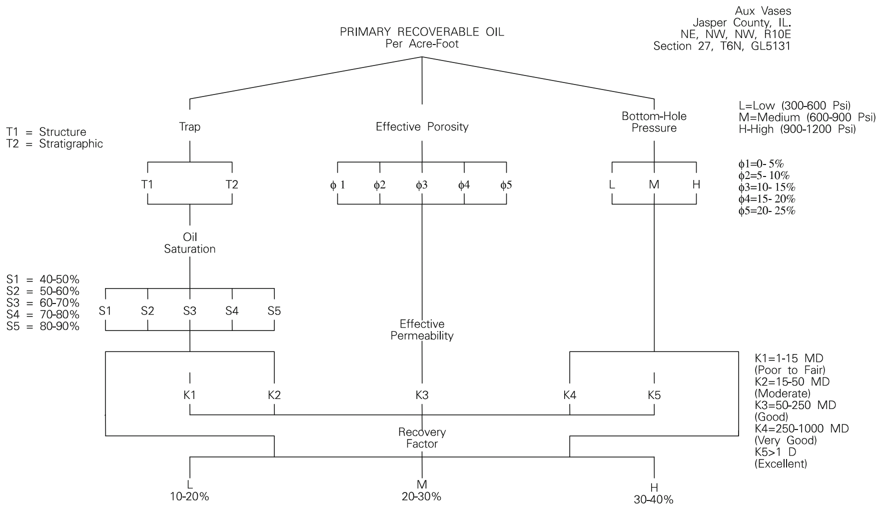

Fig. 21.2 Hierarchy for estimating the volume of recoverable oil

from deformation of crystal rock to an upward arch-shape (Anticline), to a downward trough-shape (Syncline), and fracturing and displacement (fault). A stratigraphic trap is a geologic setting resulting from termination of a reservoir rock against an impermeable formation.

Effective porosity (φ): Porosity is the volume of empty spaces in a rock which determines its capacity to store fluids (oil, gas or water). Effective porosity is the portion of pore spaces which are connected with channels large enough for fluids to circulate through them. The rest of the pores will not yield their fluids.

Effective permeability (K): Permeability is the property that permits the flow of fluids through the interconnected pores of a formation. Permeability is reported in millidarcies (MD). Absolute permeability is the ability of a rock to transmit a single fluid when it is 100% saturated with it. Effective permeability is permeability with more than one fluid present in the rock. Effective permeability is less than absolute permeability.

Saturation (S_o): Saturation is the percent of pore volume in a rock filled with a fluid (i.e. oil). Generally, a formation will produce oil if its oil saturation is more than 50%. Oil saturation ranges between 0 and 90%.

Bottom-hole pressure (reservoir pressure): The fluids in the pores of reservoir rock are under pressure which approximates the hydrostatic pressure of a column of salt water to that depth. The hydrostatic pressure gradient ranges between 0.43 and 0.47 psi ft^{-1}.

Recovery factor (RF): Recovery factor is the percent of recoverable oil or gas stored in the pore spaces of reservoir rock. The primary recovery factor for oil ranges between 20 and 40%.

Table 21.1 Effective porosity

		φ_1	φ_2	φ_3	φ_4	φ_5	Weights (w)	Midrange (φ)	w × φ
0–5%	φ_1	1	1/8	1/6	1/5	1	0.043	0.025	0.001
5–10%	φ_2	8	1	3	5	8	0.521	0.075	0.039
10–15%	φ_3	6	1/3	1	2	6	0.238	0.125	0.029
15–20%	φ_4	5	1/5	1/2	1	5	0.156	0.175	0.027
20–25%	φ_5	1	1/8	1/6	1/5	1	0.043	0.225	0.009

EV = 0.105 or 10.5%

$\lambda_{max} = 5.182$, CI = 0.045, CR = 0.040

21.3 Computation Process

The Analytic Hierarchy Process is used to determine the probability distribution for each element in the hierarchy of Fig. 21.2. To demonstrate the application of the model, the Aux Vases formation in Jasper County in the Illinois Basin was selected. Judgments on the relative importance of the factors and the relative likelihood of the outcomes were made by the second author of the original paper (see acknowledgements at the end of the chapter), who is a geologist, based on the available information on the field under study and his experience in this area. The computation process involves the following steps:

Step 1: Determine relative weights of the factors and relative likelihood of the outcomes using pairwise comparison matrices.

For demonstration purposes, the pairwise comparison matrix of effective porosity (φ), its largest eigenvalue, eigenvectors, and consistencies are shown below.

The question asked in the matrix of Table 21.1 is: which range of effective porosity is more probable for the area under study? For example, when comparing φ_1 to φ_4, we assigned a value of 1/5 which means, in our judgment, φ_4 is 'strongly' more probable than φ_1. When comparing φ_2 to φ_3 we assigned a value of 3 which means φ_2 is 'slightly' more probable than φ_3. However, in comparing φ_1 to φ_5 we assigned a value of 1 which means they are equally probable.

The numbers in the lower triangular part of the matrix are simply the reciprocals of the numbers in the upper triangular part. For example, $\varphi_1/\varphi_2 = 1/8$, whereas $\varphi_2/\varphi_1 = 8$. Both of these numbers show the dominance of φ_2 over φ_1 as well as the intensity of this dominance. Since the consistency ratio (CR) is 0.04, it means that we are very consistent in making judgments about the relative probability of effective porosity.

The principal right eigenvector (weights) of the matrix clearly shows the relative likelihood of each range of effective porosity. The most likely range of effective porosity for the area under study is φ_2 (5–10%) with a probability of 0.521; and the least likely ranges are φ_1 (0–5%) and φ_5 (20–25%) with equal probability of 0.043.

Step 2: Determining the expected value of each variable.

Table 21.2 Bottom-hole pressure (BHP)

		Range (W)	Midrange (M)	W × M
300–600 psi	L	0.226	450	101.7
600–900 psi	M	0.674	750	505.5
900–1,200 psi	H	0.101	1,050	106.0

EV = 713.25

Table 21.3 Probability distribution for the type of trap and oil saturation

	Oil saturation	Trap		Composite weights (W)	Midrange (S)	W × S
		T1 (0.167)	T2 (0.833)			
40–50%	S_1	0.124	0.129	0.128	0.45	5.76
50–60%	S_2	0.310	0.153	0.479	0.55	26.345
60–70%	S_3	0.469	0.261	0.296	0.65	19.24
70–80%	S_4	0.064	0.063	0.063	0.75	4.725
80–90%	S_5	0.032	0.033	0.033	0.85	2.805

EV = 58.875

a. Expected value of effective porosity (φ). To determine the expected value of effective porosity we use the following equation:

$$EV(\phi) = \sum_{i=1}^{5} \phi_i P(\phi_i)$$

where φ is the midpoint of each range of porosity and P(φ) is the probability of each range represented by W in Table 21.1. According to this table, EV(φ) = 0.105 or 10.5%.

b. Expected value of bottom-hole pressure (BHP). A similar procedure is used to determine the expected value of the bottom-hole pressure as shown in Table 21.2.

c. Expected value of oil saturation (S_o). Figure 21.2 shows that oil saturation range depends on the type of trap. Thus, to compute the expected value of oil saturation we must first determine the relative likelihood of each kind of trap, structure and stratigraphic and probability distribution of oil saturation for each type of trap. We then compute the overall probabilities of the saturation ranges by multiplying the probability distributions of the oil saturation by the probability of their corresponding trap as shown in Table 21.3.

d. Expected value of effect permeability (K). Relative permeability depends on effective porosity (φ), bottom-hole pressure (BHP), and oil saturation (S_o). Thus, to compute the expected value of the relative permeability for each range of values for the above variables, we compute the composite weights of each range of relative permeability as described in [5] (see Tables 21.4, 21.5, 21.6, 21.7).

e. Expected value of recovery factor (RF). Recovery factor depends on oil saturation (S_o), relative permeability (K) and bottom-hole pressure (BHP). The computation process for determining the expected value of the recovery factor is similar to (d) (see Tables 21.8, 21.9 21.10, 21.11).

Table 21.4 Probability distribution for effective porosity and relative permeability

Effective porosity						
Relative permeability	φ_1 0.043	φ_2 0.521	φ_3 0.238	φ_4 0.156	φ_5 0.043	Composite weights (W)
K_1	0.513	0.328	0.295	0.059	0.031	0.274
K_2	0.261	0.485	0.526	0.305	0.095	0.441
K_3	0.129	0.104	0.099	0.430	0.226	0.160
K_4	0.063	0.054	0.051	0.147	0.507	0.088
K_5	0.033	0.030	0.029	0.059	0.140	0.039

Table 21.5 Probability distribution for bottom-hole pressure and relative permeability

Bottom-hole pressure				
Relative permeability	L 0.226	M 0.674	H 0.101	Composite weights (W)
K_1	0.513	0.102	0.029	0.188
K_2	0.261	0.504	0.102	0.409
K_3	0.129	0.245	0.287	0.223
K_4	0.063	0.102	0.428	0.126
K_5	0.033	0.046	0.153	0.054

Table 21.6 Probability distribution for oil saturation and relative permeability

Oil Saturation						
Relative permeability	S_1 0.128	S_2 0.479	S_3 0.296	S_4 0.063	S_5 0.033	Composite weights
K1	0.513	0.081	0.060	0.034	0.030	0.125
K2	0.261	0.428	0.257	0.201	0.183	0.333
K3	0.129	0.275	0.488	0.420	0.263	0.328
K4	0.063	0.176	0.149	0.270	0.432	0.168
K5	0.033	0.041	0.047	0.076	0.092	0.046

EV = 175.47

Table 21.7 Probability distribution for relative permeability

Relative permeability	Oil saturation	Effective porosity	Bottom-hole pressure	Composite weights (W)	Midrange (K)	WxK
K_1	0.125	0.274	0.188	0.196	7.5	1.47
K_2	0.333	0.441	0.409	0.394	32.5	12.18
K_3	0.328	0.160	0.223	0.237	150	35.6
K_4	0.168	0.088	0.126	0.127	625	79.4
K_5	0.046	0.039	0.054	0.046	1,005	46.2

Table 21.8 Probability distribution for oil saturation and recovery factor

Oil saturation						
Recovery factor	S_1 0.128	S_2 0.479	S_3 0.296	S_4 0.063	S_5 0.033	Composite weights
L	0.785	0.731	0.333	0.218	0.167	0.568
M	0.149	0.188	0.592	0.691	0.740	0.352
H	0.066	0.081	0.075	0.091	0.094	0.078

Table 21.9 Distribution for bottom-hole pressure and recovery factor

Bottom-hole pressure				
Recovery factor	L 0.226	M 0.674	H 0.101	Composite weights
L	0.785	0.333	0.167	0.419
M	0.149	0.592	0.740	0.507
H	0.066	0.075	0.094	0.074

Table 21.10 Distribution for relative permeability and recovery factor

Recovery factor	Relative permeability					Composite weights
	K_1 0.196	K_2 0.394	K_3 0.237	K_4 0.127	K_5 0.046	
L	0.785	0.309	0.200	0.072	0.061	0.335
M	0.149	0.582	0.683	0.649	0.353	0.519
H	0.066	0.109	0.117	0.279	0.586	0.146

EV = 0.216

Table 21.11 Probability distribution for recovery factor

Recovery factor	Oil saturation	Relative permeability	Bottom-hole pressure	Composite weights (W)	Midrange (K)	W × RF
L	0.568	0.335	0.419	0.440	0.15	0.066
M	0.382	0.519	0.507	0.459	0.25	0.115
H	0.038	0.146	0.074	0.099	0.35	0.035

f. Volume of primary recoverable oil. The volume of primary recoverable oil from one zone can be determined using the following equation:

$$V_{(STB)} = \frac{Bxhx\phi x\, S_o\, xAxRF}{1.05 + \left(\frac{5xD}{100{,}000}\right)}$$

where

$V_{(STB)}$	is the volume of recoverable oil reserves in stock tank barrels (STB),
B	is a constant equal to 7,758 when the volume is measured in barrels and 43,560 when it is measured in cubic feet,
h	is the thickness of the reservoir rock in feet,
φ	is the porosity of the reservoir rock,
S_o	is the oil saturation,
A	is the drainage area in acres based on well spacing of 40, 80, 160, or even 640 acres,
RF	is the recovery factor, and
D	is the depth of the reservoir rock in feet

For the field under study we have:

h = 10 ft
φ = 10.5% (from Table 21.1)
S_o = 59% (from Table 21.3)
A = 40 acres
RF = 22% (from Table 21.11)
D = 2,750 ft

Thus, we obtain:

$$V_{(STB)} = \frac{(7,758)(10)(0.105)(0.59)(40)(0.22)}{1.05 + \frac{(5)(2750)}{100,000}} = 35,615\ barrels.$$

Considering the large number of variables in the model and uncertainties associated with these variables, this is a good estimate. Based on the current rate of production from a well, the actual volume of primary recoverable oil from Aux Vases formation is estimated to be between 40,000 and 50,000 barrels of oil.

21.4 Conclusions

In this chapter we have shown a simple way of solving a complex geologic problem. The advantage of the Analytic Hierarchy Process over more conventional methods for estimating oil and gas resources are as follows:

1. It provides a framework for breaking down a large and complex decision problem into smaller and more manageable decisions.
2. It leaves a permanent record of all the factors and assumptions from more ‘fuzzy’ elements at the top to very small and ‘crisp’ elements at the bottom of the hierarchy.
3. It enhances our understanding of the problem by going through it step by step.
4. It considers interactions and interdependence among all the factors influencing our decisions.
5. It incorporates data and judgments of experts into the model in a logical way.

6. One can obtain an excellent estimate of the volume of recoverable oil in a reservoir in a very short time and with the least amount of physical and financial resources.

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Chapter 22
Modeling the Graduate Business School Admissions Process

22.1 Introduction

Each year thousands of individuals seek admission to graduate schools of business in order to pursue courses leading to a master's degree such as the MBA. From late autumn through early spring, graduate admissions committees within schools of business expend enormous amounts of effort and resources to select an appropriate mix of entering students [1]. The overall decision-making process is usually complex and time consuming. Quantitative and qualitative selection criteria must be agreed upon. Thousands of pieces of application materials must be collected and evaluated. Prospective candidates must be interviewed and their performance judged. Final selections must be made [7]. The entire process must be thorough, fair, and carefully executed.

During the course of the process, difficult questions that focus on "measurables" and "intangibles" are frequently posed. Is the applicant a dependable person with high moral integrity and dedication? How difficult and challenging was the applicant's program of study? How does the committee trade off a high grade point average (GPA) against a low Graduate Management Admission Test (GMAT) score [3]? The answers to these questions depend on the judgments, preferences, and goals of the admissions committee which, in turn, reflect those of the school's faculty and administration.

In this chapter, we try to capture the overall decision-making process in the form of an admissions selection model that is based upon the Analytic Hierarchy Process (AHP) [4, 5]. Our model provides an explicit, unambiguous, and replicable way of evaluating applicants. It should help to increase the efficiency, objectivity, and fairness of the admissions process.

We recognize that many individuals involved in the admissions process may be reluctant to abdicate their own way of making selections in favor of decision making guided by a model. Indeed, they may find it difficult to incorporate their years of experience and idiosyncratic behavior into a more formalized framework.

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However, we regard this model as an aid to facilitate admissions. Although our model is based upon our experiences at the University of Pittsburgh and is tailored to meet the university's current selection process, we believe that admissions committees in other schools of business around the country, and in other graduate schools as well, will find our model appealing, insightful, and useful. We think that it can help improve communication among committee members, as well as foster better understanding of the process that is used to evaluate applicants.

22.2 The Selection Process at the University of Pittsburgh

In order to provide the reader with some background concerning graduate business admissions, we describe the current selection process that is in place at the Joseph M. Katz Graduate School of Business, University of Pittsburgh [7].

The director of admissions at the Katz School is responsible for the recruitment, evaluation, and selection of applicants. The director and her staff first collect and organize all relevant application materials (such as transcripts and recommendations) from each candidate. The amount of paper work is substantial. In recent years, over 3,000 individuals have applied to the school per year. Once a candidate's information file is complete, the admissions staff evaluates and classifies the application into one of six categories: Automatic accept, Accept, Marginal accept—accept on recommendation of director, Marginal reject—reject on recommendation of director, Reject, or Conditional accept—pending satisfaction of a condition (such as completion of a mathematics requirement). To facilitate the discussion and selection process, this classification is done prior to submitting the files to the admissions committee.

In past years, this broad classification was accomplished by comparing an applicant's undergraduate GPA and GMAT score to scales that had been developed by admissions staff members. To preserve the confidentiality of the school's admission process, these scales will not be given in detail. For example, we would automatically accept a student with a GMAT score above 625 and with GPA above 3.30 with other supporting qualifications. Each scale was divided into categories indicating levels of acceptability which helps in identifying marginal candidates or candidates who do not qualify. For those candidates who would qualify or fall in a marginal category, other criteria (such as letters of recommendation, community services, activities, essays, and work experience) would be examined further in order to ascertain if there is sufficient cause to continue the evaluation process. In addition, an interview may be requested of a candidate to obtain more information or to provide a clarification of the application materials. After all application information has been reviewed and the initial classification has been made, the application file is then submitted to the admissions committee for final review and decision.

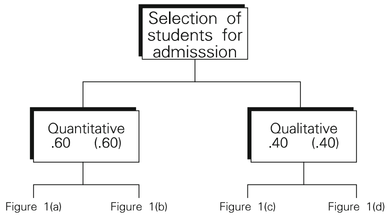

Fig. 22.1 Admissions hierarchy. **a** Undergraduate component of admissions hierarchy. **b** GMAT Component of admissions hierarchy. **c** Admission information component. **d** Work experience component of admissions hierarchy

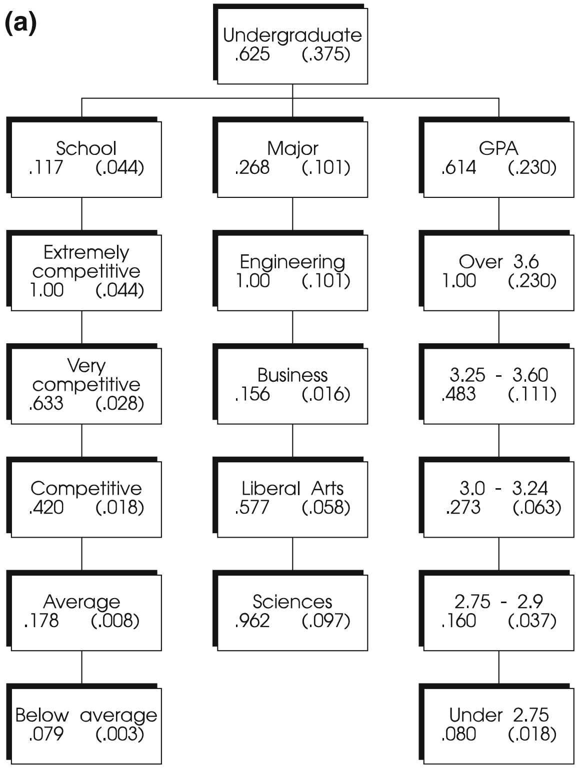

Fig. 22.1 continued

22.3 Admissions Selection Model

In the current selection process, we see that, for a single applicant, the admissions director and her staff and the admissions committee itself are confronted with a large number of tradeoffs over a diverse set of criteria. When there are several thousand

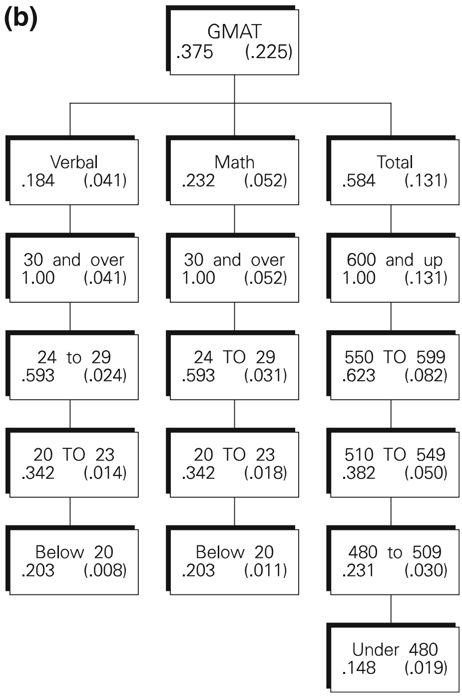

Fig. 22.1 continued

applicants to evaluate, the number of tradeoffs that must be considered is nearly intractable [1]. We believe that the current process could be made more efficient if all applicants were scored as to their performance on the same set of criteria. Scores could then be compared to "cutoff values" established by the admissions committee.

To model the process, we use a ratings hierarchy [2, 5]. With the input of the admissions director at the Katz School of Business (she is the third author of this paper) and her staff, we constructed the hierarchy shown in Fig. 22.1. In this figure, the local and global weights assigned to each criterion and each subcriterion are shown inside each box.

At the top level, we see that the goal of the process is to select the best applicants for admission to graduate school. At the second level, the goal is broken down using Quantitative and Qualitative criteria.

At level three, the Quantitative criterion is divided into two subcriteria: Undergraduate information and GMAT results. Undergraduate information is further divided into School, Major, and GPA. The School criterion measures the competitiveness of the applicant's undergraduate educational institution. Based on the university quotient index determined by the Educational Testing Service (ETS), a school is rated as Extremely competitive, Very competitive, Competitive, Average, or Below average. These rating are shown in the fifth level of the

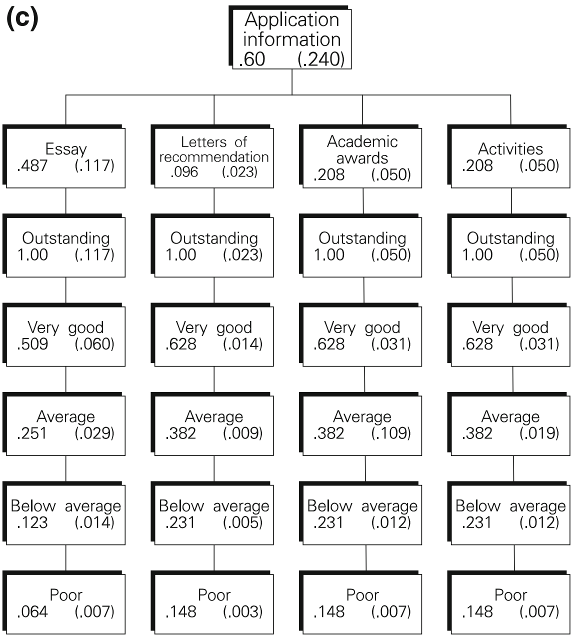

Fig. 22.1 continued

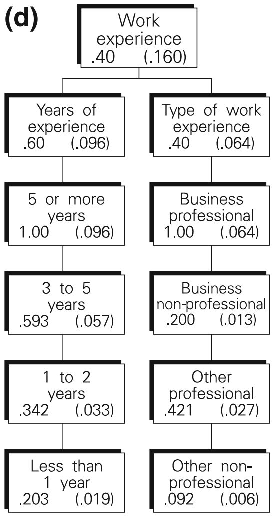

Fig. 22.1 continued

hierarchy. The Major criterion is used to evaluate applicants on the basis of their previous course of study. It was broken down into broad rating categories: Business and related majors (such as economics), Engineering, Liberal arts (for example, English, history, or political science), and Sciences (for example, chemistry, biology, or nursing). GPA is the actual average from all previous college-level work that is shown on an applicant's official transcript. The ratings for GPA are divided into five categories that range from Over 3.6–Under 2.75 points.

The other level three criterion under Quantitative is GMAT scores. This criterion is subdivided into three scores: Verbal, Math, and Total. The ETS scores the verbal and mathematical parts of the GMAT are evaluated on a scale from 0 to 60 (scores below 10 or above 46 are rare). An applicant's total score on the GMAT is not calculated by summing the verbal and mathematics scores. Rather, the total score lies between 200 and 800. To account for this, we have subdivided the Verbal and Math criteria into four ratings that range from 30 and Over to Below 20. The Total criterion is broken down into five ratings that range from 600 and Up to Under 480.

Also at the third level, the Qualitative criterion is divided into two subcriteria: Application Information and Work Experience. Application Information covers all of the data submitted by an applicant and is broken down into four subcriteria: Essays, Letters of Recommendation, Academic Awards, and Activities. Applicants are required to submit two essays and can also submit an optional third essay. These essays are read by the admissions office staff and critiqued for content, grammar, style, and general writing ability. The entire set of essays are then rated as Outstanding, Very good, Average, Below average, and Poor.

The second subcriterion under Application Information is Letters of Recommendation. Applicants are required to submit two recommendation forms that have been completed by employers, professors, or other non-related superiors. On these forms, respondents rank applicants on several questions and answer several open-ended questions. The admissions staff then rates the letters as Outstanding, Very good, Average, Below average, and Poor.

The third subcriterion under Application Information is Academic Awards. This takes into account an applicant's university awards, fellowships, membership in honor societies, and other forms of recognition for academic excellence. The overall number of awards and prestige of the awards are determined by the admissions staff and a rating from Outstanding to Poor is then assigned to the applicant. The final subcriterion, namely Activities, is handled in a similar way. An applicant's community and extracurricular activities are rated from Outstanding to Poor.

The Work Experience subcriterion is broken down into years of Experience and Type of Work Experience. Years of Experience is a straightforward category with applicants rated as having experience of 5 years or More, 3–5 years, 1–2 years, and Less Than 1 year. The Type of Work Experience subcriterion classifies applicants into four work categories: (1) a business-related job in which the applicant is considered a professional or management level employee (for example, staff accountant, credit analyst, bank manager); (2) a business-related job in which the applicant is an hourly or clerical-level worker (for example, bank teller, secretary, receptionist); (3) a non-business job in which the candidate is considered a professional (for example, doctor, nurse, dentist);and (4) a non-business job in which the applicant is not considered a professional or manager (for example, janitor, construction worker, waitress).

22.4 Implementing the Model

We envision that our AHP model would be used in the following way. At the beginning of each application period, the admissions committee would meet as a group to review the overall appropriateness of the model. The model would be updated: new criteria might be added or old criteria might be deleted in accordance with the “qualities” that committee members are looking for in a prospective student. The group would then judge the importance of criteria and subcriteria for that particular year. In our experience, using the Expert Choice computerized package [2] greatly facilitates this process. Next, the committee would compare the performance ratings at the bottom level of the hierarchy. For example, the relative importance of intensities such as Outstanding, Very good, Average, Below average, and poor for each criterion would be determined via the expert judgment of the committee.

To demonstrate this process, the current director of admissions at the Katz School of Business used Expert Choice to generate the weights shown in each box of Fig. 22.1 (Of course, the actual judgments necessary to produce the weights would be made by the admissions committee). From this figure, we see that the Quantitative criterion with a weight of 0.60 is slightly favored over the Qualitative criterion with a weight of 0.40.

Once the overall weights have been generated, individual applicants are then rated. We recommend using a spreadsheet with table lookup functions to carry out this part of the process. We illustrate this in Table 22.1 with a hypothetical set of applicants. From this figure, we see that J. Smith is rated as to her performance in each of the 12 categories. For example, in the School category, she received a Very Competitive rating. This contributed a weight of 0.028 to her overall score of 0.442. Smith’s score could then be compared with a predetermined threshold; if the score fell above this value, J. Smith would be admitted. We point out that, with our model, the maximum score an applicant could achieve is 1.00 and the minimum score is 0.124.

22.5 Conclusions

Using the AHP, we have constructed a model that can provide admissions committees with help in making complex admissions decisions. We believe that our modeling process ensures that committee members are in general agreement on

Table 22.1 Set of scores for a hypothetical set of applicants

Quantitative							Qualitative					
Undergraduate				GMAT			Application information				Work Experience	
Total	School	Major	GPA	Verbal	Math	Total	Essay recommendation	Letters of recommendation	Awards	Academic	Year of Experience	Type of work Experience
High score	**Ext. competitive**	**Eng.**	**Over 3.6**	**30 and over**	**30 and over**	**600 and up**	**Outstanding**	**Outstanding**	**Outstanding**	**Outstanding**	**5 or more year**	**Business Professional**
(1.00)	(0.044)	(0.101)	(0.230)	(0.041)	(0.052)	(0.131)	(0.117)	(0.023)	(0.050)	(0.050)	(0.096)	(0.064)
J. Smith	**Very competitive**	**Business**	**2.75–2.9**	**30 and over**	**30 and over**	**600 and up**	**Below average**	**Average**	**Below Average**	**Average**	**Less than 1 year**	**Business Professional**
(0.442)	(0.028)	(0.016)	(0.037)	(0.041)	(0.052)	(0.131)	(0.014)	(0.009)	(.012)	(0.019)	(0.019)	(0.064)
F. Davis	**Very competitive**	**Lib'l art**	**Over 3.6**	**24–26**	**below 20**	**510–549**	**Very good**	**Very Good**	**Average**	**Very Good**	**Less than 1 year**	**Business non-professional**
(0.557)	(0.028)	(0.058)	(0.230)	(0.024)	(0.011)	(0.050)	(0.060)	(0.014)	(0.019)	(0.031)	(0.019)	(0.013)
C. Jones	**Comp.**	**t.Eng.**	**3.0–3.24**	**below 20**	**below 20**	**under 480**	**Very good**	**Average**	**Below Average**	**Poor**	**5 or more years**	**Business non-professional**
(0.417)	(0.018)	(0.101)	(0.063)	(0.008)	(0.011)	(0.019)	(0.060)	(0.009)	(0.012)	(0.007)	(0.096)	(0.013)
K. Baker	**Below average**	**Sciences**	**3.0–3.24**	**24–29**	**30 and over**	**550–559**	**Average**	**Below Average**	**Poor**	**Below Average**	**1 to 2 years**	**Business Professional**
(0.471)	(0.003)	(0.097)	(0.063)	(0.024)	(0.052)	(0.082)	(0.029)	(0.005)	(0.007)	(0.012)	(0.033)	(0.064)
Low score	**Below average**	**Business**	**Under 2.75**	**below 20**	**below 20**	**under 480**	**Poor**	**Poor**	**Poor**	**Poor**	**Less than 1 year**	**Other non-professional**
(0.124)	(0.003)	(0.016)	(0.018)	(0.008)	(0.011)	(0.019)	(0.007)	(0.003)	(0.007)	(0.007)	(0.019)	(0.006)

Remark—Earlier applications of the absolute mode of Expert Choice simply weighted subcriteria weights by criteria weights, then intensities by subcriteria weights to obtain the overall weights of the intensities. In this model we have modified the former approach. To produce a ratio scale that is part of the unit priority of the top level goal would be to divide the intensities with respect to each criterion by the maximum intensity under it thus producing a unit for the intensities with respect to each criterion. The overall rating of the alternatives would then belong to a ratio scale which when normalized becomes a proportionate allocation of the unit weight of the goal to each alternative admission goals. Our approach is systematic and thorough: it effectively uses all information supplied by an applicant. The most obvious advantage of using our model for admissions selection is that it provides for consistent decision making. All applicants are evaluated on a single set of weighted criteria. This should help to reduce the subjectivity of the process. Again, we wish to emphasize that our model does not replace directors of admissions, staff personnel, and committees. Rather, it should be used as an aid in the overall decision-making process.

Early in the spring of 1991, we formally presented our model to the graduate admissions committee of the Katz School. The committee viewed our model favorably and believes that it is a tool that can be incorporated into the evaluation and selection process. The committee plans to refine the hierarchy, modify the judgments, and generate a new set of weights. Through use of the model, the hierarchy will no doubt be expanded to accommodate other factors such as graduate education and part-time work experience that need to be considered in the admissions process.

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Chapter 23
Infertility Decision Making

23.1 Introduction

Infertility is perceived as a major crisis in life. There are strong religious, cultural and societal pressures to have children. The most commonly accepted definition of infertility is the continued inability of a couple to conceive after a year. The high level of interest in the problems associated with infertility has led to the rapid development of medical technology in this area. It is one of the few specialty fields that have given rise to many emotional, ethical and legal considerations.

It is estimated that 11% of all married couples with the woman between the ages of 15 and 44 had problems with conception. An increasing number of infertile couples are seeking help. It has become more socially acceptable to seek fertility care. The number of US infertility clinics performing high-technology procedures increased from 84 in 1985 to 270 in 1992. The procedures are quite costly. Infertility has become an industry with revenues of $2 billion a year [4].

Confronted with the reality of infertility, couples have several options: remain childless, adoption, undergo in vitro fertilization (IVF) or artificial insemination, or become parents with the cooperation of a surrogate mother. The effects of childlessness and its alternatives on peoples' quality of life and on their self-perceptions provide many challenges for modern mental health professionals. Not only do we need to know what alternatives exist and their potential benefits, but also the costs and risks involved with each. Related psychological and legal issues have increasingly come to the fore. The feelings of frustration, self-doubt and negative self image are real and as painful as the medical procedures themselves. In addition to these considerations, there is another major factor—the financial cost inherent in adoption, biotechnological procedures and surrogacy. The extensive medical efforts vary from hundreds to thousands of dollars per procedure or attempt. Adoption agencies as well as "brokers" charge for their

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services. Surrogate mothers frequently assume that status from around $10,000 to $15,000. Attorneys charge anywhere from their normal hourly rate for the paper work to $10,000 or more for their "matchmaking" role.

23.2 The Alternatives

The complex problem of arriving at the best option for having a baby when it is not possible by natural process is analyzed by the Analytical Hierarchy Process (AHP). The AHP is a process of solving complex problems by logic and systemic rationality. It incorporates both the qualitative and quantitative aspects of human thought in the decision making process. The problem is defined and the hierarchy constructed in a qualitative manner and the judgments made qualitatively. It enables one to study the problem as a whole while taking into consideration the interactions between the components within the hierarchy. Six alternatives were chosen for consideration as a possible solution to the problem. A description of each alternative follows.

23.2.1 Adoption

Adoption is defined as "the overall legal process by which a parent who is not the natural parent of a child becomes legally recognized as that child's parent". It is often the last resort of infertile couples in trying to establish a family. Many of the couples have pursued medical therapies and most have rejected the legally and emotionally risky option of surrogate motherhood. In 1986 it was estimated that there were 60,000 nonrelative adoptions [6]. Until the 1970s, the most common form of nonrelative child placement was through public agencies. The most common criticism of agency adoption was that prospective parents had to sometimes wait for as long as 7 years to receive a child placement. Private or independent agencies were established in the following years. They charged ten times the fees charged by public agencies, $10,000 compared to $1,000 by the public agencies. However, they became successful as the wait period was only 12–18 months and couples were willing to pay the price for that. This form of adoption still has an intermediary, but it is more likely to be an attorney or physician rather than a state agency. The legal documents are still drawn in court and the judge must grant the adoption.

A number of court cases have considered the constitutionality of racial matching in adoption. The standard commonly used in making an assessment of whether a particular home would benefit the child is that the placement be in the "best interest of the child". Several federal courts have reviewed statutes that make racial matching a factor in adoption. In all of these rulings, the courts have held that race may be a factor, if it is in the best interest of the child, but it cannot be the automatic factor in determining placement of the child.

The changes in adoption practice and laws have made this a somewhat more hazardous alternative to childlessness than was true one or two generations ago. Yet there is no question that the majority of adoptions go through the courts without problems and result in happy families. Today, more than in previous years, there may be a need for mental health counseling and effective legal advice at the initial stage when adoption is considered and then throughout the adoption process.

23.2.2 Artificial Insemination (AIH and AID)

Artificial insemination, practiced successfully for almost a century, is a relatively straight forward and simple procedure compared to some of the other techniques developed in more recent years. There are two types in this procedure—artificial insemination by husband's sperm (AIH) and artificial insemination using donor sperm (AID). AIH is the least controversial procedure and has been widely applied in the management of infertility. The success rates for AIH depends on the clinic and varies between 0 and 50%. Benefit/cost ratios are unavailable due to inadequate data.

AID is one of the oldest and most successful therapies in infertility treatment. According to a survey published by the Office of Technology Assessment of the US Congress. over 170,000 women undergo AID and about 30,000 babies are born each year. Yet, despite the widespread practice and success of AID, there are numerous controversies regarding clinical strategies, techniques, and ethical concepts. The process should be initiated only after a thorough review of the indications, comprehensive discussion of the nature of donor screening and selection, and sensitive consideration of the emotional, social and legal implications of the process.

23.2.3 In Vitro Fertilization

In vitro fertilization (IVF), also known as the creation of "test tube babies", has been performed since the late 1970s. It involves extracting ova from the woman, fertilizing with the husband's sperm in a glass petri dish, and then after several days of growth reimplanting it in the woman's womb. One of the striking features of this procedure is the wide variation of success rates due to the complex nature of the technique and consequently the numerous variables which may impact the success. Some clinics have established a higher success rate and couples gravitate toward them. Even then the success rate is at most only 12 or 13%. It is a rather expensive procedure, costing between $6,000 and $10,000 per cycle including medication. The high cost is due to tight quality control and individual care which produce good results [7]. IVF has spawned a burgeoning industry that is almost devoid of regulation. As a result, over 200 clinics have sprung up across the country. Yet, approximately 1/3 of these clinics have not produced successful births. The current IVF market is estimated at $30–$40 million per year [3].

At present there are no specific federal statutes concerning assisted reproduction. Two bills may be introduced in the near future in Congress that could have an effect of the practice of IVF. The greatest controversy concerns the legal standing of embryos. The two sides of the controversy are that the embryos are property and, conversely, that they are humans.

23.2.4 Surrogacy

Surrogate motherhood is a method in which a contract with the surrogate is entered, usually for a fee, to bear a baby. Conception could be achieved two ways—(1) through artificial insemination of the husband's sperm and using the surrogate's egg, or, (2) implanting an embryo belonging to the couple created by IVF. The contract usually includes, in addition to the fee, the medical expenses of prenatal care and also a fee paid to the attorney who draws the contract. The surrogate's fee is about $10,000 and the attorney's fee ranges from $10,000 to $15,000 [9]. The ethics of surrogacy have been the subject of much debate because it resembles the outlawed practice of baby selling. The overall monetary, emotional and legal implications surrounding surrogacy is very high.

23.3 Procedure

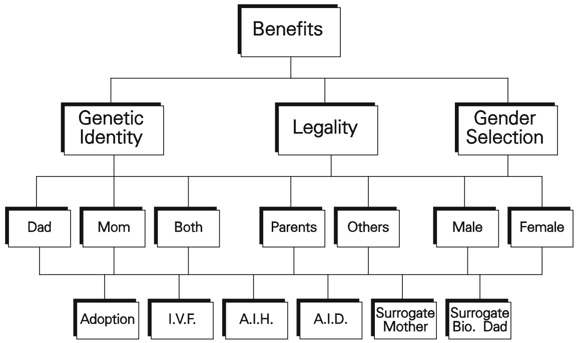
The Analytical Hierarchy Process was applied to benefit/cost analysis to obtain the overall best solution for the problem. The benefit (success) of each alternative was weighed against the cost and risk involved and a ratio of benefit/cost × risk was calculated. Three separate hierarchies were constructed for the three parameters, viz., benefit, cost and risk. The results were then integrated to obtain the best solution. The three hierarchies are discussed below:

23.3.1 Benefit (Success)

In order to achieve maximum benefits with the alternatives, the criteria considered most important were (1) genetic identity, (2) legality, and (3) gender selection (Fig. 23.1).

Genetic Identity: With advances in biomedical technology it is now possible to screen a potential mother or father for congenital defects. The probabilities of passing on a trait to an offspring can be calculated and in many instances

Fig. 23.1 Benefits hierarchy



corrective or preventative measures can be taken to avoid their occurrence in the offspring.

Legality: The development of effective therapies to treat infertility has given rise to legal implications. More medical malpractice suits were filed in the past decade than in the entire previous history of American tort law. In the last several years, Congress has taken an active interest in infertility practice. The state governments regulate infertility practice by licensure of clinics, hospitals and personnel. Law suits could arise from high-risk and invasive procedures requiring surgery. In the case of a law suit, the issue of liability must be assessed early on so that the proper defense can be pursued. Legal issues that are likely to arise should be considered by both the parents as well as others involved, like the surrogate mother.

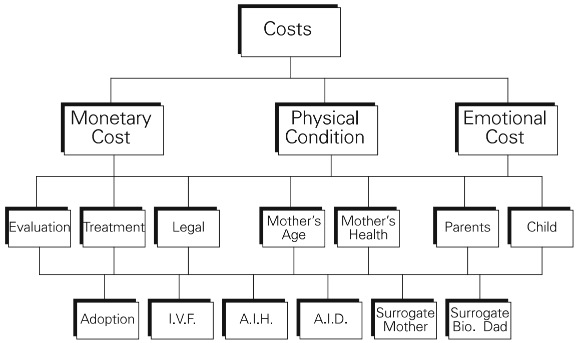
Gender Selection: This criterion gains consideration only in the case of adoption. Having made the decision to adopt, the couple is in a position to select a boy or a girl for adoption. Amniocentesis is a procedure performed during pregnancy to detect congenital defects and fetal-maternal incompatibility. However, the procedure also determines the gender of the fetus. The procedure has been criticized when, in some instances, the results have been used for the unethical purpose of choosing a baby of preferred gender.

23.3.2 Costs

There are three types of costs that were taken into consideration in determining the best alternative: (1) monetary, (2) physical, and (3) emotional costs. Monetary cost is tangible and physical and emotional costs are intangible costs. One of the characteristics of AHP is that it allows one to measure such intangible costs.

Monetary cost: In addition to considerable physical and psychological costs and time away from work, infertility treatment is expensive [2, 5]. According to Office of Technology Assessment estimates [1], the total cost to treat infertile couples ranges from $3,660 for the simplest problem to $22,200 for the whole treatment if the couple goes all the way through IVF. Not all insurance companies will cover

Fig. 23.2 Costs hierarchy



infertility as part of the benefit package; therefore, monetary cost may affect the patient's choice of treatment. In evaluating the costs involved in the entire process, three factors contributed to the expenses. These constitute the subcriteria in the hierarchy. The first expense a couple encounter is the cost of evaluating the various alternatives. These are the fees paid for medical screening in IVF and artificial insemination procedures and initial consultation fees paid to attorney or adoption agency for surrogacy and adoption (Fig. 23.2).

The next expense is the cost of the actual procedure. This includes expenses incurred with the surgical procedure in IVF and artificial insemination. Payment to the surrogate mother and her prenatal care and childbirth are incurred in the case of surrogacy. Fees paid to the adoption agency may be considered as the adoption expense.

The third expense is the legal fee paid to the attorney. Adoption requires a legal contract to be drawn. It also requires filing a petition with the court and obtaining a ruling. Laws allowing surrogacy vary from state to state. Of the states allowing surrogacy, no state has set a detailed regulatory scheme to establish the legal rights and obligation between the parties and the child. If allowed, a surrogacy arrangement would require a legal contract drawn by an attorney and court approval prior to initiation of a pregnancy.

Physical cost: Fertility rate in women is highly dependent on age. Late teen and early twenties is the most fertile period in a woman's life. Infertility increases with age and significantly so after the age of 35. The infertility rate for women between the ages of 35 and 39 is 24.6% and for women between the ages of 40 and 44 is 27.2% [8]. Hence success in medical procedures to overcome infertility is highly dependent on the age of the person carrying the baby. In the case of surrogacy where the biological mother's egg is used, the age of both the biological mother and surrogate become important. Another physical factor equally important is the state of health of the person carrying the baby.

Emotional cost: Infertility creates psychological distress in itself. In addition, they are faced with a confusing array of options, as well as uncharted ethical and legal implications that are very stressful. Support groups have proved to be valuable. Infertility makes couples more vulnerable to depression. The emotional

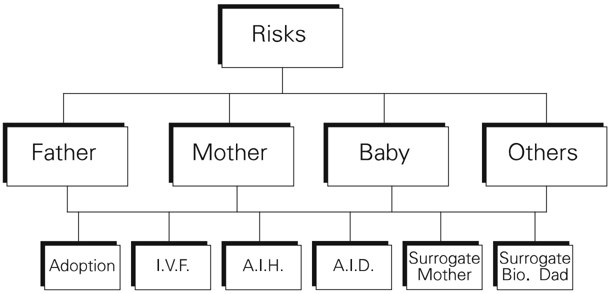


Fig. 23.3 Risks hierarchy

stress experienced during the process of adoption or any other alternative is considerable and is further enhanced by the previous status of infertility.

Emotional cost to the child also needs consideration. A child adopted at a very young age is curious to know about the birth parents and the reason why he/she was given up for adoption. In some instances the child seeks to find the birth parents and goes through emotional turmoil in coming to terms with the situation. Children adopted by a stepparent in "their best interest" often experiences emotional distress in adjusting to the new family created by the state statute.

23.3.3 Risk

All surgical procedures involve physiological risk to various degrees depending upon the type of procedure. Except adoption, all other alternatives being considered in this case require surgical procedures. The risk for all the individuals involved is considered in the risk hierarchy (Fig. 23.3).

23.4 Results

The decision reached by the AHP is discussed for each hierarchy followed by benefit/(cost × risk) analysis. Note that risk is in the denominator multiplied by the cost because one asks: which person is more at risk and which alternative has greater risk? The weighted judgments for each hierarchy were synthesized. Of the three criteria for the benefits of the process, genetic identity was the most important. IVF was found to be the most beneficial solution, but at the same time the riskiest procedure and also one of the most expensive. Surrogate mother using biological egg and sperm was found to be the least beneficial and at the same time most expensive. Artificial insemination was the most cost effective.

Table 23.1 Benefit to cost × risk ratios

	Benefits (B)	Costs (C)	Risks (R)	C × R	B/(C × R)	%
Adoption	0.112	0.154	0.044	0.007	16.47	26.92
I.V.F.	0.234	0.212	0.323	0.069	3.09	5.06
A.I.H.	0.220	0.087	0.108	0.009	23.40	38.26
A.I.D.	0.145	0.104	0.117	0.012	11.88	19.46
Surrogate mother	0.201	0.220	0.277	0.061	3.30	5.40
Surrogate Biol. father	0.088	0.223	0.131	0.029	3.01	4.92

Benefits were weighed against cost and risk taken together. A benefit/cost ratio by AHP showed AIH as the best solution for a couple who are unable to have a baby naturally (Table 23.1).

In evaluating the validity of AHP in the problem, the limitations of the model must be recognized. The results depend upon the criteria chosen to evaluate the benefits and costs and also the weights given to the judgments by the individual or individuals conducting the study. However, consistency is checked to maintain coherence among the judgments. While perfect consistency is not always possible, and often not even desirable, inconsistency of up to 10% is tolerated. If inconsistency exceeds 10%, the AHP model allows one to retrace the steps and revisit the judgments.

Given the complexity of the issues in this problem and the rapid technological advances in this area, the decision may change in the future. However, under the present circumstances, we feel that we have considered all the important and relevant criteria in the study to offer the best solution to the problem.

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Chapter 24
Deciding Between Angioplasty and Coronary Artery Bypass Surgery

24.1 Problem

This chapter is an effort to create a decision process for patients and physicians to decide between open-heart bypass surgery or the less intrusive angioplasty procedure. The model was developed with "Expert Choice for Windows vs. 9.0," including pairwise comparisons of benefits, of risks and of both procedures. The overall result slightly favors angioplasty because it indicates a lower risk potential and in addition seems to be more beneficial for the patient. The results that we determined with the AHP model, support some of the research in the medical community, but not all evidence favors angioplasty.

More than two decades ago, medical scientists discovered a new procedure to treat heart disease (see Fig. 24.1) besides using the conventional bypass surgery.

The bypass technique required a vein from elsewhere in the patients' body be taken and used to bypass the blocked artery (See Fig. 24.2).

Angioplasty is a newer procedure in which a balloon is expanded in a narrowed blood vessel, stretching the walls of the vessel to restore normal blood flow. In 1996, 666,000 (452,000 men and 214,000 women) angioplasties were performed in the U.S. Angioplasty is mainly used if a patient has coronary artery disease (CAD), which is the most common form of heart disease in the U.S. CAD means that blood vessels that feed the patients' heart are narrowed or blocked (See Fig. 24.3).

During angioplasty, a catheter (a thin, flexible tube) with a balloon at the tip is inserted into the patients' artery to widen the passageway (see Fig. 24.4). Then, the catheter is removed. After the procedure, the patient may need to stay in the hospital for a day or more.

If a patient needs treatment for serious CAD, he/she and the doctor face one of the above-described prospects. Consequently, the central question the physician seeks to answer is whether to recommend bypass surgery or angioplasty. By using the AHP, the following discussion examines the various risks and benefits that are inherent in the two methods.

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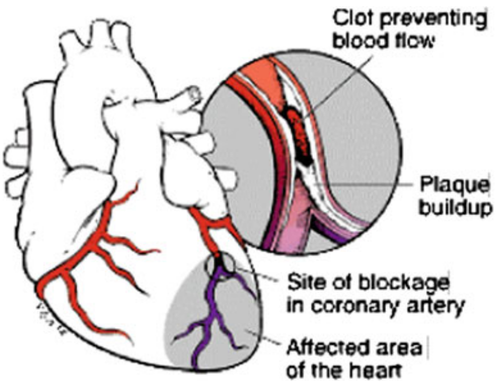

Fig. 24.1 Coronary artery disease

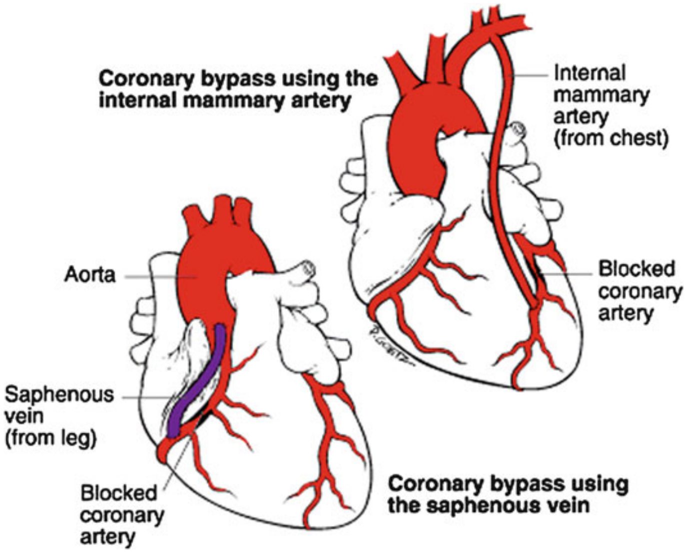

Fig. 24.2 Bypass of blocked arteries

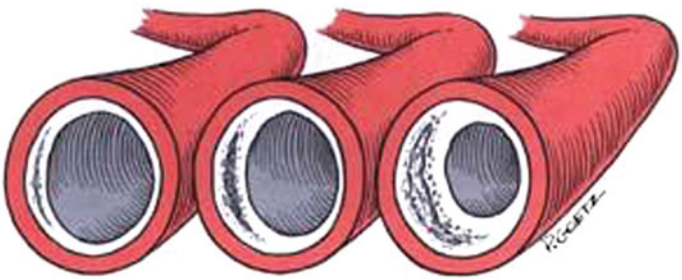

Fig. 24.3 Narrowed blood vessels

Fig. 24.4 Angioplasty

24.2 The Model

Two models were built to answer the question of whether angioplasty is preferable to the more traditional bypass operation. The first model weighs the "benefits" of the angioplasty when it is compared to the bypass; several factors were taken into consideration and weighed accordingly. The second model did the same but weighed the most important "risks" of the angioplasty when compared to the bypass procedure. The following sections will detail each level of the model and attempt to explain its importance to the decision making process and why it is included in the analysis.

24.2.1 Benefit Analysis

Under the "Benefits" model there are two sub-headings, technical and patient benefits. Each is detailed in the following synopsis. The major benefit of the angioplasty procedure is that actual surgery is not required and it is less invasive to the patient. In addition, a single angioplasty procedure is less expensive then a bypass operation.

24.2.1.1 Technical Benefits

Age: For this model, age is the most important factor (see Table 24.1). With advancing patient age, angioplasty is a more suitable option since its higher recurrence rate is less likely to matter given shorter life expectancy.

Medical Comorbidities: The following comorbidities are included:

- Hypertension
- Diabetes
- Renal failure
- Hepatic failure
- Systemic cancer
- High general risk for general anesthesia
- Poor rehabilitation candidate

The presence of any of these conditions would tend to favor angioplasty to varying degrees. For example, a bypass surgery for diabetics is better in comparison to an angioplasty because there is greater tendency for their arteries to reclog after angioplasty.

Patient Symptoms: Patient symptoms in the model include acute chest pain and congestive heart failure. Patient symptoms is one of the less important factors in the model. Patients with ongoing chest pain or congestive heart failure are better candidates for angioplasty, which can often relieve these symptoms quickly without the need for prolonged recovery following bypass.

Cardiac History: The most important factors of a patient's prior cardiac history in this model are:

- Lack of prior angioplasty and/or stenting
- Presence of prior bypass
- Lack of need for valve repair

Patients who have not had either prior angioplasty or stenting procedures are better candidates for angioplasty compared to those who have. In addition, patients who have had, and failed, a prior bypass are increasingly considered better candidates for angioplasty. Patients who need an open operation for valve repair would not be good candidates for angioplasty since they need an open procedure anyway.

Cardiac Pathology: This factor is rather important in our model (see Table 24.1). The following three elements are included in this factor:

- single vessel stenosis
- lack of complete occlusions
- less than 50% blockage of the left main coronary artery

Patients with stenosis (narrowing of a vessel) of only a single blood vessel are the best candidates for angioplasty; this is in contrast to patients who have had complete blockages of all three major arteries to the heart. If more than 50% of the left main coronary artery is blocked, it is better to have an open bypass operation.

Patient Preference: A rather less important factor is a patient's preference. The patient can have religious reasons for not allowing blood transfusions (e.g. Jehovah witnesses). In addition, it is necessary to pay attention to a patient's fear of general anesthesia and his/her refusal of surgical incision. Patients with a stronger preference for minimally invasive procedures or inability to have blood products transfused would be more strongly considered for angioplasty.

Table 24.1 Benefits hierarchy

Benefits					
Technical				Angioplasty	Bypass
0.5	*Age*	0.34		0.5	0.5
	Medical Comorbities	0.21			
	Hypertension		0.027	0.5	0.5
	Diabetes		0.027	0.624	0.376
	Renal failure		0.233	0.76	0.24
	Hepatic failure		0.245	0.93	0.07
	Systemic cancer		0.214	0.932	0.068
	High risk for Anes.		0.171	0.832	0.168
	Poor rehab. Cand.		0.084	0.849	0.151
	Patient symptoms	0.032			
	Chest pain		0.5	0.749	0.251
	Congenital Heart failure		0.5	0.251	0.749
	Cardiac history	0.174			
	Prior Angioplasty		0.089	0.406	0.594
	Prior stenting		0.121	0.395	0.605
	Prior bypass		0.606	0.653	0.347
	Lack of need for valve repair		0.184	0.101	0.899
	Cardiac pathology	0.183			
	Single vessel stenoses		0.33333	0.81	0.19
	No complete occlusions		0.33333	0.683	0.317
	<50% block of main coronary artery		0.33333	0.107	0.893
	Patient preference	0.03			
	Religious		0.455	0.885	0.115
	Anesthesia		0.09	0.708	0.292
	Surgery		0.0455	0.974	0.026
	Physician factors	0.031			
	Experience		0.455	0.5	0.5
	Skill		0.455	0.5	0.5
	Personal preference		0.09	0.5	0.5
Patient					
0.5	*Pain*	0.171			
	Narcotic use		0.5	0.86	0.14
	Depression & anxiety		0.5	0.638	0.362
	Scars	0.046		0.941	0.059
	Recovery time	0.208			
	Length of hospital stay		0.33333	0.877	0.123
	Off work		0.33333	0.877	0.123
	Length of ICU stay		0.33333	0.541	0.459
	Definitiveness of Procedure	0.487			
	Addt'l test & monitoring		0.162	0.32	0.68
	Addt'l procedures & surgery		0.838	0.12	0.88
	Expense	0.088			
	Insurance		0.33333	0.685	0.315
	Hospital		0.33333	0.655	0.345
	Society		0.33333	0.624	0.376
	Composite Priorities			0.528	0.472

Physician Factors: The physician factors in the model are rather unimportant. They include experience, skill, and personal preference. Physicians with more experience and greater skill with angioplasty would tend to recommend angioplasty. Experience matters, especially in complex procedures like angioplasty. Standards recommend that a physician perform at least 75 angioplasties per year and that an institution perform at least 200 of these procedures annually.

24.2.1.2 Patient Benefits

Pain: Compared to open-heart bypass surgery, angioplasty is less painful. The general consensus among patients is that this is a sometimes uncomfortable, but not painful, procedure. The patient may feel some twinges in his/her chest when the balloon is inflated, but once the blockage is compressed, the pain should disappear. Additionally, the patient may also feel nauseous, feels his/her heart "skip" or have a headache during the procedure; these are all normal, brief side effects. Afterwards, the patient will probably feel some discomfort for the day of, and following, the procedure. Pain medication is available, and he/she should let his/her doctor or nurse know if he/she is experiencing additional discomfort.

Scars: Incisions and scars are almost invisible when the patient undergoes angioplasty. As described in the introduction, an angioplasty does not need opening the body of the patient. Instead, the catheter fed into the body only needs a tiny hole in the leg, near the patients' groin.

Recovery time: Patients recover faster from an angioplasty. A major benefit of using angioplasty is that this procedure is a less invasive approach compared to bypass surgery because it is carried out through a tiny catheter inside the artery. Since the surgery itself takes only a few hours, patients return to a normal lifestyle (e.g. work) much faster. In addition, angioplasty involves only insertion of a thin, balloon-tipped plastic tube (the catheter), through a small incision in the leg. Therefore, it is less traumatic than open-heart surgery. The patient is able to leave the hospital considerably earlier than those who undergo bypass surgery. However, in the long-term, because of repeating the procedure, angioplasty patients are more likely to spend more time in the hospital than bypass patients do. Nowadays, the procedure of angioplasty using a stent diminishes the total days a patient has to stay in the hospital.

Definitiveness of procedure: Although the first angioplasty was conducted more than twenty years ago, there is still a degree of insecurity using this method. A recurring blockage (restenosis) occurs in about one-third–one-half of the successful angioplasty procedures performed. A doctor may choose to do additional angioplasty, incorporating the stenting procedure to minimize the chance of restenosis. Sometimes bypass surgery is warranted. If a patient has received a stent, they will be on an anti-clotting medication for several weeks. A stent is a tiny mesh tube that is left at the blockage site to help the artery stay open. They may also receive special medication to help the arteries to heal. Following the angioplasty, a patient will need to see the doctor for a stress EKG to measure how effectively the blockage was eliminated. Also the patient would be put on an exercise program and his/her doctor would likely to see him/her several times a year to make sure no more blockages have occurred.

Expense: This analysis does not outline the quantifiable costs explicitly because these costs are about the same for both procedures. The angioplasty treatment costs less originally, but clots form so often that it has to be repeated, which increases the total costs.

24.2.2 Risk Analysis

Angioplasty blocks the artery briefly when the balloon is inflated and consequently the artery collapses immediately, which can trigger a heart attack if the blood supply to the heart muscle is already too severely restricted. The procedure can also damage or puncture an artery. In addition, the risk of blood clots increases slightly (as the catheter touches the artery wall). Another disadvantage of the method is that the artery frequently becomes blocked again, requiring another angioplasty or surgery.

There are in fact some potential negative side effects, which can occur after the angioplasty, e.g. the arm or leg (at the insertion site) may feel numb or cold, there may be signs of infection (redness or oozing) appearing at the insertion site or there may be chest pain and discomfort.

In addition, angioplasty patients have a higher likelihood of experiencing angina (chest and arm pain) and exercise-induced ischemia (insufficient supply of blood to a particular organ or tissue). In order to become angina-free over time, patients must undergo repeat procedures of revascularization (through either angioplasty and/or bypass surgery). This in turn increases all the other mentioned risks connected to both techniques. However, a new method of angioplasty using a stent can decrease repeated revascularizations.

The preceding factors along with others were considered in the model. As in the "Benefit" model, the "Risk" model also has two sub-headings, patient and technical risks. The technical risks include five equally weighted factors. However, the patient risks include eight separate factors with varying weights according to their importance.

24.2.2.1 Technical Risks

Medical Comorbidities: The first heading under the technical risks is comorbidities, which includes the anethesia risk and the rehabilitation risk for this procedure. The anethesia risk is weighted much higher because although it is an often practiced technique, and one can never be sure of a patient's reaction to it (see Table 24.2).

Cardiac Pathology: The next technical consideration is the pathology of the procedure. Under this heading there are three equally weighted factors. These

Table 24.2 Risks hierarchy

Risks					
Technical				Angioplasty	Bypass
0.5	*Medical comorbidities*	0.2			
	Anesthesia risk		0.885	0.093	0.907
	Rehabilitation risk		0.115	0.245	0.755
	Cardiac pathology	0.2			
	Single vessel stenoses total		0.33333	0.5	0.5
	Lack of vessel occlusion		0.33333	0.208	0.792
	Total vessel blockage		0.33333	0.863	0.137
	Physician factors	0.2			
	Experience		0.364	0.5	0.5
	Skill		0.493	0.5	0.5
	Personal preference		0.143	0.5	0.5
	Cardiac history	0.2			
	Prior angioplasty		0.326	0.658	0.342
	Prior stenting		0.326	0.033	0.967
	Prior bypass		0.348	0.5	0.5
	Age	0.2		0.5	0.5
Patient					
0.5	*Death*	0.438		0.1	0.9
	Blood loss	0.02			
	Anemia		0.246	0.086	0.914
	Transfusion		0.754	0.097	0.903
	Infection	0.07			
	Sternal wound infection		0.923	0.016	0.984
	Groin wound infection		0.077	0.274	0.726
	Lung	0.059			
	Pulmonary edema		0.626	0.136	0.864
	Pneumothorax		0.374	0.105	0.895
	Sudden Occlusion	0.218		0.887	0.113
	Arrhythmia	0.059			
	Atrial		0.079	0.31	0.69
	Ventricular		0.921	0.684	0.316
	Disease recurrence	0.1			
	Chest pain		0.104	0.942	0.058
	Myocardial Infarction		0.896	0.928	0.072
	Vascular complications	0.037			
	Femoral Pseudoaneurysm		0.64	0.906	0.094
	Venous insufficiency in lower extremeties		0.36	0.039	0.961
	Composite Priorities			0.445	0.555

factors are: single vessel stenosis, lack of total vessel occlusion and total vessel blockage.

Physician Factors: This technical consideration is rather arbitrary and depends on luck of the draw more than anything else. Under this heading there are three factors. The most important is the skill of the physician performing the procedure. This is closely followed by a related factor, the experience of the surgeon. Both are followed by the personal preference about what he/she believes is the most effective procedure.

Cardiac History: The cardiac history of the patient to receive the treatment is one that cannot be forgotten when considering a choice between the two procedures. The risks under cardiac history are equally weighted between three factors. The first is whether the patient has ever had an angioplasty performed before. The next factor is similar and that is whether the patient has any prior stenting. The final historical factor is if the patient has ever undergone a bypass procedure.

Age: The final technical consideration when weighting the risks of the two procedures is the age of the patient at the time of the procedure. Obviously, due to its less intrusive nature, angioplasty is preferred for older patients and for the same reason for younger patients who hope to avoid the bypass procedure.

24.2.2.2 Patient Risks

Death: With any type of medical procedure there is always the chance of death. This factor is weighted very heavily in the model, because it is a very significant risk factor for the patient.

Blood Loss: The risk of blood loss is very low in angioplasty, therefore it has the lowest weight in the model (see Table 24.2). Two types of blood loss are considered; the most important is loss that would require transfusion.

Infection: Even in today's pristine operating conditions, there is always a chance of infection when a surgical procedure is performed. The most common in these two procedures is the sternal infection that can result from a bypass procedure. With the angioplasty one associates groin infection where the incision is made during the procedure.

Lung: Difficulties can arise in a patient's lung when the bypass procedure is performed. Pulmonary edema is the problem that has the largest weight in the model, closely followed by pneumothorax.

Sudden Occlusion: Sometimes, following angioplasty or bypass surgery, one of the major coronary arteries can become suddenly blocked. This can lead to death of the cardiac muscle that it supplies, which is more common with angioplasty.

Arrhythmia: This is a condition that occurs when the heart muscle is irritated and its electrical activity altered. The more common form is atrial arrhythmia followed by ventricular arrhythmia, with the latter being much more dangerous to the patient. Atrial arrhythmia is not uncommon after bypass surgery and is less common after angioplasty. Fortunately, ventricular arrhythmia is rare following both procedures.

Disease recurrence: There always exists the danger of recurrence of the symptoms. The model lists the two most common: myocardial infarction and chest pain. In general, disease recurrence is much more common following angioplasty.

Vascular Complications: The final factor in patient risks is vascular complications, or injury to various blood vessels in the body. The two factors included under this injury are femoral pseudoaneurysm and venous insufficiency. The former is more common after angioplasty, while the latter is more common after bypass. Unfortunately a femoral pseudoaneurysm often requires an additional surgical procedure to repair it.

24.3 Patients for Model

To test the model, it was appropriate to use it on two actual cases for which the decision as to whether to proceed with bypass or instead use angioplasty was known. The first patient was a 52-year-old man with all the symptoms associated with the onset of heart disease. He is a smoker, asthenic, with high cholesterol and most importantly a strong family history of coronary artery disease. This patient had a history of mild chest pain when he exerted himself, such as when shoveling snow. One day he experienced severe chest pain and subsequently had a heart attack. Imaging at the hospital indicated severe triple vessel disease with complete occlusion of two to three vessels. Clinically this patient would be selected for the bypass procedure because of the high risk of recurrence, the severity of his disease and because he had complete occlusions. When this patient's characteristics were put through the AHP model, it also favored the bypass procedure.

The second clinical case was an 87-year-old woman, who remained an active non-smoker and had no family history of heart disease. She was a diabetic who experienced mild renal failure. With no prior history of chest pain, she developed severe chest pain while walking. Imaging at the hospital indicated 85% stenosis of the left main coronary artery, the other three vessels showed no damage. Clinically this patient would be selected for angioplasty due to her low risk of recurrence, high risk for surgery given her age and diabetes. The AHP model also favored angioplasty for her.

In general, angioplasty has slightly greater benefits (0.528 versus 0.472) and slightly lower risks (0.445 versus 0.555) (see Tables 24.1 and 24.2).

24.4 Conclusion

As pointed out in the previous sections, angioplasty appears to be a more effective and successful treatment if a patient suffers from coronary artery heart disease. Nevertheless, it is not a cure. The patient needs to change any unhealthy habit (also called risk factor) that helped create his/her heart problems in the first place. Some risk factors are smoking, eating too much fat and salt, and not getting enough exercise. Making changes to reduce the risk factors can help keep the patients' heart condition from getting worse and may even improve the health of his/her heart.

The outcome of the analysis using the AHP indicates only a very slight tendency to rather do an angioplasty instead of the traditional and more definitive open-heart bypass surgery. This outcome appears to be a consequence of the great similarities in the effects of the two surgical techniques (e.g. long-term survival rates and quality of life measures).

However, the decision whether to do an angioplasty or an open-heart bypass surgery should consider each patient on an individual basis. Doing either procedure itself must be considered on an individual basis as well.

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