AN INTERACTIVE MULTI-CRITERIA DECISION MODELING TOOL USING THE ANALYTIC HIERARCHY PROCESS METHODOLOGY

by

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE (BUSINESS ADMINISTRATION)

in

THE FACULTY OF GRADUATE STUDIES

(Department of Commerce and Business Administration)

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

December 2000

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DE-6 (2/88)
This thesis presents an interactive software tool for applying multi-criteria decision making using qualitative criteria. The tool provides an easy to use implementation of the model based on the Analytic Hierarchy Process (AHP). This process allows decision-makers to set priorities and make choices based on their value judgments, objectives, knowledge and experience in a way that is consistent with their intuitive thought process. The software tool is designed to be simple, interactive and user-friendly so as to minimize any apprehension or resistance to its use. It enables a balanced, comprehensive, consistent and sustainable approach to the appraisal of policy and program proposals.

Following a discussion of the AHP methodology, we illustrate the application of the tool. Three illustrative applications were developed to demonstrate how the tool could be used to model diverse real world decision-making situations: 1) Comparing communities on the basis of their contribution to human well-being; 2) Choosing between alternative programs for a charitable organization and 3) Choosing between sustainable development options.
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INTRODUCTION

The purpose of this thesis is to present an effective and easy-to-use tool to evaluate alternative choices based on qualitative multiple criteria. These criteria are usually conflicting and descriptive in nature.

Making decisions is an everyday occurrence, yet it is important because making the wrong decision may affect one's life for years to come. People make decisions because there is a need to choose among alternatives. How to choose among the alternatives requires judgment about making the best choice.

An evaluation of the merits based on different alternatives requires assessment of the expected outcome of each alternative, which requires input data and selection criteria. The process underlying decision making is very complex, and seems so trivial with the human brain. We are making decisions constantly in our daily life even without our awareness.

This thesis develops an approach that helps decision makers. A specialized software tool was developed to demonstrate a simplified way to present a highly complex decision-making process involving human behaviour.

This software allows the user to input data visually and the results are displayed instantly. It also allows the user to do "what if" analysis by varying the input interactively. The following example provides an illustration of the terminology used in this model. The example involves the decision whether to bring an umbrella to work. The alternatives would be 'yes' or 'no'. A simple criterion would be to listen to the weather report. The information given by the weather report is the input data.

1.1 MULTI-CRITERIA DECISION MAKING

Most real life decisions involve multiple criteria or multiple objectives. For example, when buying a car, most people do not make the purchase decision based on price alone, they may also look at the style, gas consumption, and reliability of the vehicle. These are the major components of a model based on multiple-criteria decision making.

It is relatively easy to make decisions based on a single objective. In the case of buying a car, if the price is the only criterion, then choosing the lowest price seems to be the right choice. However, there are far more complex problems involving many criteria; these require a systematic approach to assign priority weights to the criteria. Therefore, there is a need for a decision support tool for analyzing complex problems.

1.2 IDST – INTERACTIVE DECISION SUPPORT TOOL

Management Science offers many analytic tools for dealing with the "hard" aspects of operations research such as linear programming, Integer programming, queuing theory, and
stochastic processes. These are great tools for improving the efficiency of industrial and management processes; however, when dealing with decision making that involves human behaviour and value judgments, we need to look at the “soft” aspect of operations research. Analytic Hierarchy Process (AHP) (Saaty 1980) is a method that was developed to handle the subjective component of decision making.

The Analytic Hierarchy Process methodology has substantial theoretical and empirical support extending from the study of human judgment processes by cognitive psychologists. It uses a hierarchical structure of decision making, pair-wise relative comparison of elements in the hierarchy, and a series of redundant judgments. The use of redundancy permits accurate priorities to be derived from verbal judgments even though the words themselves may not be very precise. This ability to use words to compare qualitative factors and derive ratio scale priorities that can be combined with quantitative factors provides a valuable tool for solving complex problems. (Anderson, Sweeney and Williams, 1992)

AHP has been applied extensively in project planning and environmental policy making. Min (1994) used AHP for the planning of the location of airport facilities. Yin and Cohen (1994) applied AHP in identifying regional goals and policy concerns associated with global climate change.

AHP is distinguished from other approaches, such as goal programming, conjoint analysis, and multiple-attribute utility theory as described by Saaty (1980), as it provides a measure of consistency in the user input by employing the eigenvalue method. This has the benefit of improving the accuracy of subjective judgments, which are the major components of decision making. Besides the eigenvalue method, there are other ratio scaling methods for extracting priorities in hierarchy structure. De Jong (1984) proposed the logarithmic least square approach (LLSM) as a statistical description of inconsistency in pair-wise comparison matrices. He showed that LLSM produces best linear and unbiased estimators under a number of realistic and practical models. He also stated that LLSM solutions are a first-order approximation to these eigenvector solutions.

There are commercial software packages, such as Expert Choice (www.expertchoice.com) and Logical Decisions (www.logicaldecisions.com), available to implement the analytic hierarchy process. However, to meet future application demands, such as the capability of conducting surveys on the Internet, the custom software IDST was developed.

The following are the major features of IDST:

1. The major criticism of using AHP is that the user has to go through a great number of pair-wise comparisons to make decisions even for problems of medium complexity. This problem could be overcome by designing and developing IDST with some of the more objective components set up as defaults in the program. The user could bypass many of these comparisons to save the trouble of going through too many input steps.

2. IDST provides a turnkey system that is tailor made for the project, thereby minimizing the number of steps in operating the software. The design is interactive and user friendly, which is crucial in gaining user support for the project.
3. Further insights and enhancements could be gained in developing custom software. For example, would the priority scales be different if the input preferences were in decimals instead of integers? What effect would it have to add a module to generate minimum spanning trees in order to reduce the number of pair-wise comparisons.

METHODOLOGY

2.1 ANALYTIC HIERARCHY PROCESS

The Analytic Hierarchy Process, developed by Saaty in the management science discipline during the 1970s, is a useful decision theory. It involves the measure of subjective and objective value judgments. It provides a systematic approach to process pair-wise comparisons to arrive at a scale of priorities among sets of alternatives. To apply this approach, it is necessary to break down a complex unstructured problem into its component parts. Then we arrange these parts, or variables, into a hierarchic structure; assign ratio scales to pair-wise comparisons on the relative importance of the variables; and synthesize the ratio scales into priorities to determine which alternatives have the highest ranking. To improve the accuracy of measuring the priority rankings, redundant pair-wise comparisons are included in the process. To understand Analytic Hierarchy Process, one should first understand the concept of relative measurement and pair-wise comparison.

2.11 Relative Measurement

When beauty is abstracted
Then ugliness has been implied;
When good is abstracted
Then evil has been implied.

So alive and dead are abstracted from nature,
Difficult and easy abstracted from progress,
Long and short abstracted from contrast,
High and low abstracted from depth,
Song and speech abstracted from melody,
After and before abstracted from sequence

Lao Zi, 570 B.C.

The concept of relative thinking existed in Chinese literature over 2000 years ago. People can usually respond more effectively when they are asked to make relative comparisons in a descriptive question (Saaty 1980). For example, "Is your life better or worse than before?" rather than a question about the absolute level of happiness they have achieved. The result would be more meaningful on a relative scale than an absolute scale. The concept of relativity may be alien to most people, but it is necessary to measure and combine tangible and intangible elements. Very often there are no standard scales to measure intangibles; therefore the use of
ratio scales (Saaty 1993), which adopts the concept of relative measurement, seems appropriate. Relative measurement is the basis of absolute measurement, which we often overlook. Absolute measurement is a common way of measuring tangibles based on some manmade scales, such as meter, degree, or mile, for example. To make an absolute measurement, we still have to rely on making measurements based on relative comparison. For example, current market values are usually based on comparing what other people were willing to pay in the past. From the physical science perspective, we call an object that is not moving 'stationary' in relation to the earth. However the object could be moving at a great speed relative to some other objects, such as the moon. The absolute term 'stationary' does not exist simply because every object in the universe is in constant motion relative to some other object.

Man-made absolute measurements very often hinder our understanding of intangibles, such as human behaviour and value judgments. In science, linearity is also a common man-made assumption — the distance between point A and point B on earth is usually assumed to be a straight line. This is not always true because the earth is spherical. Extending this concept to the measurement of time can call into question statements by some scientists who claim objects are billions of years old. Therefore, I would try to avoid using these common assumptions in the study of human behaviour, value judgments, preferences, perceptions and many other intangible elements that do not have standard scales.

2.12 Pair-wise Comparison

Another important concept in decision-making is the pair-wise comparison. People tend to make better judgments when they put two things together and compare their preference for these items (Saaty 1980). For example, when people are asked to rank five different items, they mentally compare two at a time until they come up with a ranking order. Studies (Miller 1956) show that, in general, people can simultaneously deal with only a few facts – it is difficult to do mental comparisons if there are more than seven items. Complex decisions usually involve many criteria; therefore a systematic approach of applying the concepts of relative measurement and pair-wise comparison is crucial for decision-makers dealing with issues that affect the well-being of many people.

A motivation for the AHP process follows (Saaty and Vargas 1991):

Assume that we are given n stones, C₁,..., Cₙ whose weights w₁,..., wₙ, respectively, are known to us. Form the matrix A with pair-wise ratios whose rows give the ratios of the weights of each stone with respect to all others. Multiply this on the right by the vector of weight w of weights. The result of this multiplication as shown is nw.

Thus to recover the scale from the matrix of ratios we must solve the problem Aw = nw

\[
\begin{bmatrix}
\frac{w_1}{w_1} & \frac{w_1}{w_2} & \ldots & \frac{w_1}{w_n} \\
\frac{w_2}{w_1} & \frac{w_2}{w_2} & \ldots & \frac{w_2}{w_n} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{w_n}{w_1} & \frac{w_n}{w_2} & \ldots & \frac{w_n}{w_n}
\end{bmatrix}
\begin{bmatrix}
w_1 \\
w_2 \\
\vdots \\
w_n
\end{bmatrix}
= \begin{bmatrix}
w_1 \\
w_2 \\
\vdots \\
w_n
\end{bmatrix}
\]
or \((A - nI)w = 0\). This is a system of homogeneous linear equations. It has a nontrivial solution if and only if the determinant of \((A - nI)\) vanishes, i.e. \(n\) is an eigenvalue of \(A\). Now \(A\) has unit rank because every row is a constant multiple of any other row, and all its eigenvalues except one are zero. The sum of the eigenvalues of a matrix is equal to its trace, and in this case the trace of \(A\) is equal to \(n\). Thus \(n\) is an eigenvalue of \(A\), it is the largest principal eigenvalue and associated with it we have by construction a nontrivial positive solution \(w\). To make \(w\) unique, we normalize its entries by dividing by their sum. Thus, given the comparison matrix, we can recover the scale assuming \(a_{ij}\), for all \(i\) and \(j\), are based on exacted measurements. In this case, the solution is any column of \(A\) normalized. Note that \(A\) satisfies the reciprocal property \(a_{ji} = 1/a_{ij}\), for all \(i\) and \(j\), and \(a_{ii} = 1\), for all \(i\). In addition, \(A\) is consistent, i.e., its entries satisfy the condition \(a_{jk} = a_{ik}/a_{ij}\), for all \(i, j,\) and \(k\). The entire matrix can be constructed from a set of \(n\) elements that form a chain across the rows and columns.

In practice, \(a_{ij}\) are based on subjective judgments and will deviate from the “ideal” ratios \(w_i/w_j\) and therefore the equation \(Aw = nw\) will no longer hold. However, we can still derive the priority vector based on two facts of matrix theory.

If \(\lambda_1, \ldots, \lambda_n\) are the eigenvalues satisfying the equation \(Ax = \lambda x\) and if \(a_{ii} = 1\) for all \(i\), then

\[
\sum_{i=1}^{n} \lambda_i = n
\]

The second fact is that if one changes the entries \(a_{ij}\) of a positive reciprocal matrix \(A\) by small amounts, then the eigenvalues change by a small amount.

Based on these two facts, if the diagonal of a matrix \(A\) consists of ones and if \(A\) is consistent, then small variations of the \(a_{ij}\) keep the largest eigenvalue \(\lambda_{\text{max}}\) close to \(n\), and the remaining eigenvalues close to zero.

Our problem now becomes \(A'w' = \lambda_{\text{max}}w'\) where \(\lambda_{\text{max}}\) is the largest or principal eigenvalue of \(A'\). To simplify the notation we shall continue to write where \(A\) is the matrix of pair-wise comparisons. It has been demonstrated that the eigenvector corresponding to the largest eigenvalue of the matrix provides the alternatives (Saaty 1988); i.e. if an alternative is preferred to another, its eigenvector component is larger than that of the other. Thus we obtain from the matrix of paired comparisons a vector of weights that reflect the relative importance of the various factors.

### 2.13 Consistency

The AHP methodology does not require that judgments be consistent or even transitive. The consistency (or inconsistency) of the judgments is revealed at the end. One might ask, if the judgments were totally random in nature, what kind of consistency would the AHP interpret them to have? The consistency of such random judgments should be much worse than the consistency of informed judgments and can be used to compare and evaluate the goodness of the consistency of informed judgments.
Note that if we have \( w = (w_1, \ldots, w_n)^T \), the matrix whose entries are \( w_i/w_j \) is a consistent matrix which is our consistent estimate of the matrix \( A \). If \( a_{ij} \) represents the importance of criterion \( i \) over criterion \( j \) and \( a_{jk} \) represents the importance of criterion \( j \) over criterion \( k \), then \( a_{ik} \), the importance of criterion \( i \) over \( k \), must equal \( a_{ij}a_{jk} \) for the judgments to be consistent. \( A \) itself need not be consistent; i.e. \( C_1 \) may be preferred to \( C_2 \) and \( C_2 \) to \( C_3 \), but \( C_3 \) is preferred to \( C_1 \). What we would like is a measure of the error due to inconsistency. A necessary and sufficient condition for \( A \) to be consistent is that \( \lambda_{\text{max}} = n \). \( \lambda_{\text{max}} \geq n \) always holds according to the two facts of matrix theory stated above. As a measure of deviation from consistency we use the consistency index (C.I.):

\[
\text{C.I.} = \left( \frac{\lambda_{\text{max}} - n}{n-1} \right)
\]

This index has been randomly generated for reciprocal matrices of different orders. (Saaty 1988).

The average (over Saaty’s simulations) of the resulting consistency indices (R.I.) are given by:

<table>
<thead>
<tr>
<th>( N )</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.I.</td>
<td>0.00</td>
<td>0.52</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
</tr>
</tbody>
</table>

The ratio of the C.I. to the R.I. for the same order matrix is called the consistency ratio (C.R.). Based on AHP applications in varied contexts involving complex problems using expert judgment, a consistency ratio of the order of 0.10 or less appears to be a reasonable level of consistency (Saaty 1980). When this level is exceeded, revisions of the judgments are recommended.

Thus, given a pair-wise comparison matrix, we have a measure to assess the extent of its deviation from consistency. When such deviations exceed the limits specified, we say that there is a need for the provider of the judgments in the matrix to reexamine his or her inputs.

Note that in making the estimates, and to keep the comparisons relevant, an individual has to keep in mind all the elements being compared. It is known (Miller 1956) that people can simultaneously deal with only a few facts – it is difficult to do mental comparisons if there are more than seven items. Otherwise, consistency adjustments would be large compared with the derived value, which then cannot be considered reliable. If this is so, then how are we able to have measurement across wide classes of objects? The answer is by hierarchical decomposition.
2.14 Hierarchy

The elements are grouped ordinally (as a first estimate) into comparability classes of about seven elements each. The elements with the largest weight in the class of lighter weight elements is also included in the next heavier class and serves as a pivot to uniformize the scale between the two classes. One divides the weights of the elements into a second group by the weight of the pivot elements and multiplies them by its weight in the first. In this manner the weights of the elements in both classes become commensurate and the two classes can then be combined. The procedure is repeated from a class to an adjacent one until we have all the elements appropriately scaled.

The pair-wise comparisons are arranged in a matrix, referred to as a reciprocal matrix, because the \(a_{ij}\) element of this matrix is \(1/a_{ij}\) or the reciprocal of the \(a_{ij}\) element. The reason for this can be understood by comparing two stones. If one stone is estimated to be \(k\) times heavier than another, the other, which serves as the unit of comparison, must be \(1/k\) times as heavy as the first. A reciprocal matrix also has the property that its principal diagonal elements are unity reflecting the fact that a factor when compared with itself should obviously produce a judgment of “equal importance”. Thus, if a level includes \(n\) factors, a total of \(n(n-1)/2\) comparisons are needed because diagonal elements and the reciprocals are entered automatically.

2.15 Scale Comparison

The scale of absolute magnitudes used to indicate the relative judgmental preference of one factor over another is shown in Table 2.2. The use of this scale is contingent on the satisfaction of the assumption that the factors being compared are similar orders of magnitudes. When a factor does not appear strictly comparable with another, clustering techniques can be applied so the comparisons are made possible at the level of the clusters within the hierarchy.

<table>
<thead>
<tr>
<th>Table 2.2 Scale for Comparisons</th>
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<tbody>
<tr>
<td>1</td>
</tr>
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<td>3</td>
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<tr>
<td>5</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>2,4,6,8</td>
</tr>
</tbody>
</table>
2.16 Clustering

When there are many elements involved in a hierarchy, it is convenient to break them down into cluster groups according to their similarity or relative importance. The results of each cluster can then be aggregated by linear combination of priority weights of each element within the hierarchy. Saaty (1980) stated that mathematically clustering should produce the same results as an overall approach would.

To obtain the overall priority scores of the alternatives for a single hierarchy, we assume that there are m criteria and n alternatives in the hierarchy. Let \( W \) denotes the nxm priority matrix of alternatives with component \( W_{ij} \) equals to the weighting of alternative \( i \) on criterion \( j \). Let \( P \) denotes the priority vector of the m criteria, then the overall priority vector \( S \) is given by

\[
S_i = \sum_{j=1}^{m} P_j W_{ij} \quad \text{for } i = 1 \text{ to } n
\]

2.2 DESIGN AND DEVELOPMENT OF SOFTWARE TOOL

The software tool designed to demonstrate this model is based on the WYSIWYG "What You See Is What You Get" concept. It was developed using Microsoft Visual Basic. There are two user levels involved in the operation of the software. The first level allows the user to operate the tool in an intuitive user-interface. The first screen shows criteria in the form of a tree structure. The number beside each criterion represents the weight assigned to this criterion. Clicking the 'immediate parent' line above can modify these numbers and then the input screen will be displayed. The input screen will show the questionnaires for each pair-wise comparison of two items. If there are 5 items being considered, then 10 sliders in total will appear on the input screen. By moving the slider left or right to indicate the preference for one of the two items being compared, the user can interactively see the changes in weights associated with the 5 items. The consistency ratio is also displayed on the right hand side of the input screen.

The right hand side of the first screen displays the alternative choices with the ranking scores for each choice. This represents the overall ranking scores of the choices and interactively changes after the closing of each input screen. The user can perform "what if" analysis similar to that of an electronic spreadsheet by moving any of the sliders at will. The impact on the overall priority will be updated instantaneously on the output screen.

Please refer to Figures 3.1 and 3.2 below to illustrate these ideas.

The second level allows the user to customize an application by creating an input text file with the titles of the criteria and alternatives. At this level, the user will require the ability to formulate the decision hierarchy and will need some Visual Basic programming skills.

The methodology of calculating the eigenvalues and eigenvectors are outlined in Hamilton (1994), and are based on the Gaussian Elimination algorithm as described in Hillier and Lieberman (1980).
3.1 EXAMPLE 1: USING HUMAN WELL-BEING MEASUREMENTS TO COMPARE HABITAT CHOICES

![Hierarchy for measuring human well-being](image1)

Figure 3.1 Hierarchy for measuring human well-being

![Input screen for pair-wise comparisons](image2)

Figure 3.2 Input screen for pair-wise comparisons
If the objective of public policy and community planning is to improve human well-being, then there is a need to define and measure it. Abraham Maslow’s hierarchy of needs is used to provide indicators that measure human well-being. The impact of different community structures on individual well-being was measured against the hierarchy of needs using Thomas Saaty’s Analytic Hierarchy Process. An easy to use illustration software tool was developed using Microsoft Visual Basic. The software illustrates and compares human well being individually under different community structures.

3.11 Background

The history of human ecology was very much marked by "development" during the past century. Countries were classified as developed, developing, or underdeveloped based on economic indicators such as Gross National Product (GNP) or Gross Domestic Product (GDP). Although economic well-being does not necessarily ensure human well-being, it is an essential component. Cummins (2000) concluded that money buys happiness to the extent that external resources permit optimal functioning of Subjective Well-being (SWB) using the Homeostatic Theory. His model predicts significantly different levels of SWB for people who are rich, people on average Western incomes, and people who are poor. He described Homeostatic Theory as follows:

Homeostatic theory proposes that SWB is held within a narrow range determined by personality. Experience with the environment also impacts on this system but its influence is attenuated by two sets of buffers. The internal buffers comprise beliefs in perceived control, self-esteem, and optimism. The external buffers comprise resources, such as personal assistance, that ameliorate that impact of potentially negative events.

There are many quantitative methods to measure economic well-being; however, measuring human well-being presents research challenges because there is no generally accepted operating definition. Human well being has different meanings from various perspectives. In this context of evaluating social polices, it includes Subjective Well Being (SWB) and Quality of Life (QOL). It also includes the objective components put forward by the Human Development Report, which include longevity, economic development, and education level.

There have been many studies on quality of life, subjective well-being, and happiness. Sirgy (1986) provides quality of life definitions from the perspective of economics, marketing, ecology, environment, public health and community psychology. More recently (Diener, 1995), (Diener, Suh and Oishi, 1997) (Michalos, Zumbo and Hubley, 2000) and (Hegerty, 1999) have completed studies relating to the quality of life which are described below.

Besides the Homeostatic Theory of SWB, Diener (1995) defines SWB in terms of how people evaluate their lives, and includes variables such as life satisfaction and marital satisfaction, lack of depression and anxiety, and positive moods and emotions.

Daniel Haybron (2000) proposes a philosophical perspective in his study of happiness. He suggests that we need to establish an understanding of what we want from a theory of
happiness, which can then help us to answer which view, or views, of happiness best satisfy our theoretical and practical needs.

There is a lack of computational tools to measure and combine qualitative data with quantitative data. Most of the empirical studies on QOL and SWB are based on surveys and questionnaires that are analyzed using statistical tools. These studies do not measure human well-being from a holistic perspective.

The Satisfaction with Life Scale (SWLS) (Diener, Suh and Oishi, 1997) measures SWB through self-report surveys in which the respondent judges and reports life satisfaction, frequency of pleasant moods, or frequency of pleasant emotions using a scale that ranges from one to seven. SWLS is a five-item instrument designed to measure global cognitive judgments of one’s life. The sum of the number of the five items assigned by the respondent reflects his level of satisfaction with life.

Michael Hagerty (1999) used the Maslow’s hierarchy-of-needs theory to predict development of Quality of Life in countries over time. He developed a new database that includes time-series on statistical data for 88 countries as indicators for his Quality of Life study.

Since measuring human well-being consists of both qualitative and quantitative components, it is a challenge to develop computational tools using a holistic approach. To the best of my knowledge, this is the first time that the Analytic Hierarchy Process methodology has been used to measure human well-being.

3.12 Proposed Definition

In order to define human well-being, an examination of human nature is helpful. According to Abraham H. Maslow, a psychologist, human beings instinctively have many needs that can be classified into a hierarchy consisting of five levels:

1. The lowest level consists of physiological needs such as food, lodging, air, and water. The first two can usually be obtained from earnings through participation in economic activities.

2. The second level is safety needs. Human beings want to feel financially secure so that their physical needs can be sustained, which is usually achieved through the accumulation of wealth. They also want to live in a protected environment free from predators and other dangers.

3. The third level is love and sense of belonging, such as the desire for a spouse, a family, and identification with a community or society.

4. The fourth level is self-esteem—there are two versions of esteem needs: 1) the need to be recognized by others as important and successful. Some people can achieve this by making donations to charities, wearing brand name clothes, driving luxury cars and living in expensive homes, which are symbols of success. 2) the need for self-respect such as the feeling of self-confidence, competence and achievement.
5. The highest level is called self-actualization. People at this level feel that they have achieved their goal of being themselves and doing what they like to do.

It is noteworthy that, except for the physiological needs, the higher levels of needs are based on personal feelings and perceptions. For example, some people feel that they are financially secure when they have earned one million dollars, but it may be two million dollars or more for others.

I would like to propose these five levels of needs as the indicators of human well-being. Sirgy (1986) proposed that QOL goals involve a dimension of hierarchical goals varying from lower-order psychological and safety-related goals to higher psychological goals, in which the lower-order goals are more dominant than higher-order ones.

Sirgy (1986) also proposed that societal institutions be designed to serve human developmental needs. There are institutions that serve physiological needs (e.g., water works, utilities, agriculture); safety needs (e.g., health services, police, emergency facilities, judicial system); social needs (e.g., leisure, recreation facilities, social products and services), esteem needs (e.g., employment services, intra-organization services), and self-actualization needs (e.g., arts, theory, aesthetics).

The method of measuring human well-being I propose does not require that the lower level needs be satisfied before the higher level needs are met. If improving individual well-being means satisfying more of these needs, then improving human well-being in a public policy and planning context would mean that most people's lives would be improved. This method of measuring human well-being could be applied to project evaluation and to comparisons of different social policies.

Extending Maslow's theory to the case of development, sustainable development (the safety need from a society's perspective) would be more of a concern for the developed countries than the underdeveloped countries. This is simply because developed countries have lower level needs met through economic development. Hagerty's study (1999) showed significant agreement with this extension on Maslow's theory relating to the sequence of need achievement.

3.13 Sample Application

Community A is a cooperative type where most people live and work within the neighborhood. Individual member's needs, such as food, lodging, education, and medical services are guaranteed and distributed by the community. In addition, working members receive nominal wages for out-of-pocket expenses. The community promotes and enforces the public interest ahead of self-interest. The gap between the rich and poor is narrow. A modern commune called Nan Jie Cun in Henan province, China, which I visited this year, is an example of such a community.

Community B is very much like our current social structure—a consumer-oriented community. Most people have to find jobs outside the community in which they live and have to compete to earn their living. The community does not discourage people from fighting for their own interests. The gap between the rich and poor is wide.
John Doe is trying to determine his preference for the two communities described based on his assessment of the relative importance of the five well-being measures and his assessment of how each community satisfies these objectives. The software helps to reveal the following relative preferences on a scale of 1 to 9 as defined above. The symbol ‘>’ implies greater preference and ‘<’ implies lesser preference:

<table>
<thead>
<tr>
<th>Level</th>
<th>Preference</th>
<th>Community A</th>
<th>Community B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt;3</td>
<td>Community A is moderately preferred to B because it provides more of the basic physiological needs (level 1) as shown in Figure 3.3 above.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&gt;5</td>
<td>Community A is strongly preferred to B because there appears to be more job security and future needs would be guaranteed.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&gt;7</td>
<td>Community A is very strongly preferred to B because there is more cooperative spirit and a strong sense of identity in Community A.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&lt;5</td>
<td>Community B is strongly preferred to A because the jobs would be more challenging and contributions have a better chance of being recognized.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>&lt;7</td>
<td>Community B is very strongly preferred to A because there are more opportunities for doing what you like and fully realizing your potential.</td>
<td></td>
</tr>
</tbody>
</table>

The results given by the computer model after the computational analysis are as follows. If John Doe is single and just started working with the preferences as shown in Figure 3.2, the first scenario, the overall ranking scores of his well-being would be Community A - 72% and Community B - 28% as shown in Figure 3.1.
If John Doe has established a family and a successful career, as in the second scenario shown in Figure 3.4 above, the overall ranking scores of his well-being would Community A – 33% and Community B – 67% as shown in Figure 3.5. The higher the percentage associated with an alternative, the more favourable the choice.
The method for measuring human well-being involves the concept of relative measurements and pair-wise comparisons. These are important concepts in understanding the process of decision-making. This approach closely resembles that of the decision maker who mentally compares and weighs the complex and often conflicting criteria in ranking policy alternatives.

When two things are put side-by-side, people can easily compare them by revealing their preferences. For example, when comparing the physiological and safety needs in Maslow's theory, which is more important? On a scale of 1 to 9; 1-the same; 3-moderate; 5-strong; 7-very strong; 9-extreme; 2,4,6,8 are in-between. Among the 5 levels of needs, there are 10 pairs in total to be compared; Levels 1&2, 1&3, 1&4, 1&5, 2&3, 2&4, 2&5, 3&4, 3&5 and 4&5.

The human well-being was decomposed according to Maslow's hierarchy of needs and the hierarchy was set up as shown in Figure 3.1 above. The screen in Figure 3.2 above shows the 10 combinations of pair-wise comparisons of the five level hierarchy. The user slides the point towards the item of greater importance as described in section 2.2 above. A computational analysis is then applied to the 10 relative preferences. The outcome is the percentage score for each need level as shown in Figure 3.1 above. The main purpose of using Maslow's theory in this study was to separate well-being into its major components -- namely the five levels of needs. This model enables us to gain insight into the fact that in terms of the two community structures, neither is absolutely good or bad. Each community has a different impact on the well-being of the individual depending on his or her preferences, perceptions and perspectives.
3.2 EXAMPLE 2: CHOOSING BETWEEN PROGRAM OPTIONS IN A CHARITABLE ORGANIZATION

3.21 Background

The Jewish Family Service Agency (JFSA) of Vancouver offers a wide range of programs to meet the needs of individuals in crisis, seniors, immigrants and the public. Faced with limited financial resources and increased demand for its services the agency sought to develop a process to assess its program offerings and review new programs. Puterman (1998) developed a multi-criteria decision-making framework for new program evaluation and resource allocation between existing programs. The approach was based on the AHP perspective. Criteria were chosen to reflect basic human needs as described in the previous example in addition to community needs and agency needs.

3.22 Setting up the Hierarchy

The criteria chosen are described below:

A. Does the service meet basic human needs by providing food, shelter, clothing or financial support?

B. Does the service meet the needs of individuals and families in crisis?

C. Does the service enhance individuals and families ability to achieve financial or physical independence by providing for example, job or volunteer experience, transportation or companionship?

D. Does the service enhance individuals and families ability to achieve emotional health by increasing self-esteem, dignity, worth and self respect or improving family life and interpersonal relations?

E. Does the service preserve the community through increased participation or by increasing individuals and families sense of belonging?

F. Does the service increase the community’s awareness of social problems such as abuse, poverty, disabilities and concerns of intermarried couples?

G. Does the service increase the external visibility of the agency?

H. Is the service unique because it meets the cultural and religious needs and concerns of members of the community who may find similar services inaccessible or who prefer receiving the service in a cultural context, or because this service is unavailable elsewhere?

I. Does the service recover costs or raise funds?

J. Does the service support a sufficient number of people?
The first step would be to formulate a decision hierarchy into clusters based on the above criteria, which basically fall into three major groups:

1) Impact on the individual and family;
2) Impact on the community
3) Impact on the organization.

The following Figure 3.6 illustrates the hierarchy for evaluating charity programs based on the three major groups:

![Figure 3.6 Hierarchy for evaluating charity programs](image)

### 3.23 Inputting Preferences

By clicking one of the lines corresponding to each of the ten criteria, an input screen will be displayed as follows (Figure 3.7):
Figure 3.7  Pair-wise comparison between two programs

The above input screen compares the merits of the two programs in providing basic human needs. It indicates that the Immigrant Job Placement program is moderately more preferable in providing basic human needs.

By clicking one of the lines corresponding to each of the three groups, an input screen will be displayed as follows (Figure 3.8):

Figure 3.8  Input preference for the sub-criteria
By clicking one of the lines corresponding to “Select a Charity Program”, an input screen will be displayed as follows (Figure 3.9):

![Input Screen](image.png)

Figure 3.9 Input preferences for the major group

The overall priorities of the two programs, the abused women’s shelter and the immigrant job placement centre are instantly displayed in Figure 3.6. The results in this example indicates the job placement centre would be a better choice since it has a higher score when compared to the abused women’s shelter.

3.24 Discussions

It was found in practice that the AHP methodology was difficult to apply because of the large number of comparison required and an ad hoc approach was developed based on subjective weightings to evaluate programs. The tool IDST proposed in this thesis presents a potentially very effective method for implementing this process in a systematic way.

3.3 EXAMPLE 3: DECISION MODELING FOR SUSTAINABLE DEVELOPMENT

To enable policymakers to deal with issues other than those of economic development, this tool will enable the modeling of priorities based on the three imperatives of sustainable development (Robinson 1997). This is a descriptive approach that explains a decision, as opposed to the prescriptive approach of performing decision analysis for the decision-makers.

It is primarily a communication tool to enable decision-makers to reveal to the people they represent how they make decisions. The decision-makers can illustrate the important criteria that affect the decision and the weights they put on each criterion to come up with the decision.

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This would indicate if the weights are subjective, i.e. based on their own preferences and perceptions, or based on committee or group debates and discussions.

There are difficulties in dealing with intangible and subjective components of decision-making. Various special interest groups place different weights on the three imperatives, namely economic, social, and environmental issues. For example, an environmentalist tends to focus more on environmental criteria, whereas business groups tend to put more weight on economic criteria. The interactive decision modeling tool illustrates these differences and shows how they affect policy decisions.

3.31 Background

The study on the Sustainable Development for Hong Kong (SUSDEV21) was commissioned in 1997. The objective was to develop a tool that would assist decision-makers to incorporate the concept of sustainability in the future development of Hong Kong. The study involved defining sustainable development, developing the guiding principles and sustainability indicators. Guiding principles were necessary to serve as the link between the social indicators and the objective of sustainable development. After extensive public consultation, the result of the study proposed the following as the definition of sustainable development. (Hong Kong SAR 1999a)

Sustainable development in Hong Kong balances social, economic and environmental needs, both for present and future generations, simultaneously achieving a vibrant economy, social progress and better environmental quality, locally, nationally and internationally, through the efforts of the community and the Government.

3.32 Guiding Principles

In order to measure the impact of policy proposals on the sustainability objective, 39 indicators were proposed and grouped under the following 8 guiding principles:

1. Economy
2. Health and Hygiene
3. Natural Resources
4. Society and Social Infrastructure
5. Biodiversity
6. Leisure and Cultural Vibrancy
7. Environmental Quality
8. Mobility
3.33 CASET - Computer Aided Sustainability Evaluation Tool

A decision support tool entitled CASET (Computer Aided Sustainability Evaluation Tool) was developed to evaluate the sustainability implications of major project and policy proposals. The system logic of CASET is based upon a series of questions linked to relevant indicators. The response to the questions triggers a series of indicators. The user then inputs responses about the predicted magnitude and direction of change of the indicator. With the help of CASET, scenarios are formulated for the proposal being considered and tested against a set of indicators. The changes as predicted on each indicator were shown on the Sustainability Evaluation Diagram (SED) and Sustainability Evaluation Report (SER).

CASET is not intended to be a modeling tool nor an expert system. It mainly provides consistent, disciplined and cross-sectoral information on how a project is related to the sustainability objective. The information is primary quantitative measurements and constitutes the objective components of decision-making.

The decision-makers may have to consider up to 39 indicators in the SED and SER together with other subjective components, such as value judgments and political considerations, before making a decision.

The decision modeling tool presented here will help decision-makers to overcome these difficulties and will complement the deficiency of the CASET tool.

3.34 Hierarchy

To model the ranking of different policy alternatives using the tool, a decision hierarchy was set up (Figure 3.10). This hierarchy is based on the hypothetical example provided in the Final Topic Report 7/8 (Hong Kong SAR 1999c). The SER report provided the objective component and defaults for the model. The subjective components are the weights assigned to the five relevant guiding principles for this example, namely Economy, Health and Hygiene, Natural Resources, Environmental Quality, and Mobility as shown in the Figure 3.10 below.
The results on the right-hand side of Figure 3.10 represent the overall priorities of the three scenarios.

- **Baseline**: the current state of the indicators before implementing the project proposal.
- **Proposal**: the future state of the indicators after implementing the project proposal, for example in three to five years from now.
- **Control**: the future state of the indicators if the proposal were not implemented.

By clicking one of the lines corresponding to each of the sub-criteria, an input screen will be displayed as follows (Figure 3.11):
The input screen displaying the pair-wise comparison of the guiding principle of sustainability is shown in Figure 3.12 below:

![Input screen for pair-wise comparisons](image_url)

**Figure 3.12  Input screen for pair-wise comparisons**
3.35 Discussion

This model was demonstrated to the SUSDEV21 executive committee in summer 2000. They found this novel approach of assigning weights to the sustainability indicators very useful. The turnkey approach of IDST reduced their resistance towards using the software as a decision support tool. The current CASET tool has no capability of assigning weights to the indicators and has to rely on the mental judgement of the decision-makers.

AREAS OF FURTHER INVESTIGATION

The design of IDST enables many future potential developments. The modification of IDST would allow Internet users to participate in surveys based on AHP. IDST can also be enhanced to consolidate individual beliefs in order to reflect society’s perspective. One of the possibilities would be to aggregate the results in Example 1 and correlate the criteria in Example 3 with automatic links between the two modules. This will allow decision-makers to decide how the practice of sustainable development can improve quality of life.

There are two basic approaches to consolidate individual results to form a group decision: consensus and the Delphi method (Saaty 1980). Consensus improves confidence in priority values by using group discussion to bring results in-line with the majority preferences. The Delphi method involves anonymous responses from group members on specially designed questionnaires. The results are then analyzed as suggested by Basak and Saaty (1993).

It could also be a valuable tool for media presentations. News reporting may often lack objectivity because the journalists and reporters often reveal their own value judgments. This model could potentially be part of the reporting where the reader or viewer could see results based on their own value judgments as well. This multi-perspective approach could train people to be more objective and less radical in their worldviews.

CONCLUSION

It has been demonstrated that the challenges of measuring human well-being and the difficulties of implementing sustainable development in decision making may be overcome using IDST. The specially designed user interface minimizes resistance to its use. The flexibility of its design, including the potential for Internet-based surveys, enables future empirical studies on these issues. It could also be an effective communication tool so that decision-makers can have their decisions better understood by the people they represent.

The application of the Analytic Hierarchy Process made the descriptive approach to decision analysis possible. This approach allows people to understand where they differ by examining the components that form their decisions. IDST allows decision analysis based on AHP to be more accessible to the general public. This tool could potentially open up a whole range of possibilities for government, private industries and personal uses. Government departments could adopt a more balanced approach to development instead of the single objective of economic development. Businesses may adopt a multi-objective approach of balancing the
needs of consumers, shareholders, employees and environmental concerns instead of the traditional single objective of “profit maximization”. For individuals, the tool will allow them to evaluate things based on multiple perspectives. There are many levels of human needs besides the single objective of pursuing wealth.

I hope that this provides an analytic tool for the study of social sciences and humanity. People can reveal their own preferences, perceptions and perspectives in ways that can easily be understood in order to resolve conflicts.
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