THE APPLICATION OF UTILITY THEORY TO THE VALUING OF AIR POLLUTION-RELATED HEALTH EFFECTS:

Three Proposed Pilot Studies on Subjective Judgments of Asthma

Prepared for

Harvey M. Richmond
Environmental Protection Specialist
Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, NC

Prepared by

Adam C. Johnston
EPA NNEMS Graduate Student Intern
University of North Carolina, Chapel Hill
Dept. Environmental Science and Engineering

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EXECUTIVE SUMMARY

Utility under uncertainty is a field of decision theory that has received increasing attention in the field of public health. This report reviews its uses during the past decade and suggests its possible use in national ambient air quality standard setting procedures. It is common practice in standard setting to assess the likelihood of air pollution effects on sensitive populations. One such population, asthmatics, is selected in this report and the relationship between air pollution and asthma is reviewed. In addition, three possible pilot studies are suggested which use aspects of utility under uncertainty theory to elicit values concerning asthma health effects. The results of such studies would provide U.S. EPA with information for their ambient air quality standard setting and increase the awareness of the possible uses of utility theory in such applications.

INTRODUCTION

During the past twenty years significant efforts have been made to create a method of measuring health status on a single scale for comparisons over time, and between individuals and groups in an attempt to overcome what Bergner (1) calls the "single-continuum dilemma." This dilemma has arisen in the past because of the diverse and complex nature of many health states, making it difficult to make comparisons between individuals in the same or different health conditions. Such a means of measurement would be useful in making decisions, creating health indices, setting priorities, and developing a basis for regulatory standards. One area which has been suggested for this purpose is utility theory. Spitzer (2) in his keynote address to the Portugal Conference on the measurement of quality of life stressed the importance of utility theory in such applications by stating that "utilities and trade-off methods hold enormous promise in the field of public health, [and] there is a strict discordance between the logical strength of the utility strategy for the assessment of quality of life or health status and the extent to which the methods have been demonstrated."

As Spitzer has stated, the health field appears to be an excellent area for the application of utility theory and its methods. In many fields, when an individual is making a decision or comparing a series of possible outcomes, comparable units representing the worth of each outcome, such as dollars, lives saved, or cases of disease averted are clear. In the health field, however, effects are often refered to in intangible terms such as pain and suffering (3). These outcomes do not have obvious, uni-dimensional measurable values which can serve as a single unit of comparison. This may frequently cause difficulties. In addition, in policy or regulatory environments it is desirable to compare these intangibles with each other or with more concrete ideas of money or time. To overcome this problem, it is possible to employ some aspects of utility theory as a means of valuing outcomes which have varying likelihoods of occurrance, but do not have inherent quantifiable measurements. This area of utility theory is referred to as utility under conditions of uncertainty and is considered a specific application of the broader theory. Within this specific application it is common to use various assessment techniques to elicit subjective values from an individual for any number of different outcomes. These values, or utility levels, can then be compared on a single scale. Utility, therefore, can be thought of as a subjective measurement whereas money and lives saved are uni-dimensional, objective measurements (4). For this reason, utility has become particularly useful in the health field; it is often used in the field of medical decision making to compare possible health outcomes, treatments, or health states. In this case, utility theory is used to provide a means of comparison through the assignment of probabilities and preference weights to the various possible outcomes.

Only a small volume of workin the field, however, has been associated with health-related environmental decisions. Keeney, a major contributor to the field of utility under uncertainty, and collegues have done some work related to environmental decisions, especially in the area of air pollution control and regulations (5,6). There is, however, much room for additional work to be done.

This report, therefore, reviews the theory, biases, and various methods of assessment of utility under uncertainty, and its applications to health-related outcomes. In addition, the specific health state of asthma and its association with air pollution is discussed and a series of possible studies applying utility analysis techniques to air pollution health effects valuing are suggested. Specifically, three pilot studies are outlined which attempt to provide information to the U.S. EPA on the valuing by asthmatics of air pollution-related health effects. These studies are intended as a means of displaying the ease of use of utility assessment and to provide specific information on subjective valuing of asthma and its symptoms by asthmatics. Furthermore, such studies may provide valuable input during the assessment of effects on sensitive populations as a part of national ambient air quality standard setting.

UTILITY THEORY

Utility theory has its roots in more than two hundred years of economic thought. One of the early developers of the idea of utility was Daniel Bernoulli. In 1738 he developed the St.Petersburg Paradox which provided a source for early discussions about utility. The paradox involves a game in which a coin is tossed n times until it comes up heads at which time the player of the game is paid $\$2^n$. The question that must be asked , therefore, is how much should an individual be willing to pay to play this game? It would be reasonable to predict the amount by calculating the expected payoff of the game by summing the products of all the possible payoff outcomes and their respective probabilities of occurance. As it turns out, the expected payoff for this game is an infinite sum. The player, therefore, should be willing to pay anything to participate in this game. Intuitively, however, this does not make sense. Bernoulli, therefore, stated that one should consider the "moral worth" of an alternative and not just its expected monetary value. In other words it could be said that in the process of gaining an item, a point is reached where an additional item is not worth as much as the item preceeding it. For example, if you receive a pizza you place some value on that pizza. The second and third pizza that you receive you may also value equally; however, you will quickly reach a point where an additional pizza is not worth as much to you as those previously received. Money can be considered similarly. The value or utility of money (or pizzas) will decrease as more is gained. If this idea can be accepted then a finite solution to the above game may result.

The St. Petersburg Paradox showed a need for the idea of utility. It wasn't until the 1940's, however, when von Neumann and Morgenstern published Theory of Games and Economic Behavior (7) that utility theory under uncertainty became established. Watson and Beude (8) state that von Neumann and Morgenstern developed utility "to prescribe how people should evaluate options about which they were uncertain." Specifically, von Neumann and Morgenstern thought that individuals should assign utility values to possible outcomes. Then, when faced with decisions which include risky alternatives, the individual should select the outcome with the highest expected utility. The expected utility is the product of the assigned utility level and the probability that the outcome will occur.

The theory is justified by a series of axioms. These axioms include assumptions about how an individual ought to behave while making a decision under uncertainty, and, therefore, are normative. They do not, however, describe how individuals actually behave. If a subject accepts these axioms, then his only rational action during decision making is to select an outcome with the maximum expected utility. This point, however, is considered somewhat controversial. It is often argued whether individuals should even necessarily conform to the axioms. Furthermore, when they do not behave consistently with the axioms, it is often out of choice and not because they are "being fooled by cognitive illusions" or not considering all the dimensions (9).

Certain specific decisions which are often cited by scholars are the various paradoxes that go against the axioms. The axioms of utility theory assume that the value of an outcome and the probability of its occurance are independent. This assumption, however, may not always be true in real decision making as shown by the results of the Allais Paradox. The paradox involves several choices between gambles. In the first an individual is offered a choice between (A) a guaranteed payoff or (B) a chance at a higher payoff that also involves a very small risk of receiving nothing. In the second decision the individual must choose between (C) a chance at receiving a moderate payoff with some risk of receiving nothing or (D) a much greater prize at a slightly higher probability of receiving nothing. If the expected payoffs are calculated for each case, it appears that the best choices are (B) and (C). When this problem is actually presented to people the predominant choices by far are (A) and (C). The problem involved here is that most people overweigh the very small probability that exists in (B) and would rather receive a moderate guaranteed payoff than risk getting nothing for a chance at a much higher payoff. Furthermore, even when the inconsistency of their choice is pointed out, many people stay with their original choice. This is a case in which the axioms are clearly violated by choice. The original idea of utility and the modern von Neumann-Morgenstern uncertainty utility therory still have not resolved this paradox; however, it should be remember that axioms do not attempt to describe decisions exactly but instead provide a target for rational behavior. For the purpose of this paper these controversies are set aside, but it should be noted that the field of utility under uncertainty is still under development and its validity is often questioned and discussed by both its critics and proponents.

The following is a list of axioms compiled from three sources (9-11) and should not be considered exhaustive. These axioms are not all equally important. Hershey and Baron (12) state, for example, that the two most important axioms are transitivity and independence and Bell and Farquhar (9) include continuity as a basic axiom also. Each of the axioms, however, is necessary at least in some specific case.

Transitivity - given the outcomes A, B, and C, in a preference relationship such that A is preferred to B and B is preferred to C, then it is assumed that A is preferred to C.

Independence - if A is preferred to B then a gamble where A is the prize is preferred to a gamble where B is the prize if the two gambles have equivalent alternatives to the prize and equal probabilities of outcomes.

Continuity - it must be possible for indifference to exist between a certain outcome, C, and a pair of uncertain outcomes, A and B, given that C is preferred to B and A is preferred to C.

Reduction of Compound Uncertain Events - a mixture of gambles may be reduced or simplified using standard probability manipulations without affecting preferences.

Connectivity - an individual is able to make judgments about preferences when faced with a gamble (i.e. preferences exist).

Sure Thing - preferences for gamble A over gamble B should not depend on events for which A and B have identical outcomes.

Substitutability - indifference exists between a certain outcome, C, and one formed by substituting for C with an outcome which may be a lottery judged equivalent to C.

Monotonicity - given a choice between two gambles with equivalent outcomes, A and B, the gamble with the higher probability of winning the better outcome is preferred.

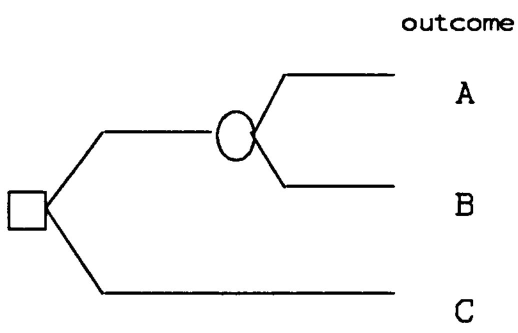
Completeness - outcome values and probabilities are required to determine preferences between uncertain outcomes.

Boundedness - outcomes cannot be infinitely bad or infinitely good.

The validity or strength of a number of these axioms is often questioned. Further, as mentioned above, the axioms are considered controversial because individuals in their usual decision making process do not necessarily adhere to these axioms and it is also argued whether an individual even ought to conform when able. There may, in fact, be very rational reasons for violating an axiom. A brief discussion of the psychology and biases which cause these differences is presented later in this paper.

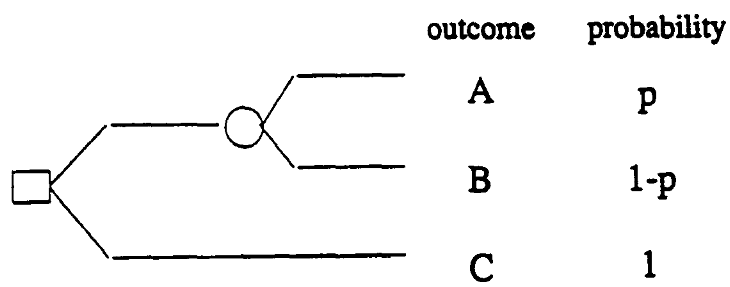
The usually intended result of the application of the theory and the axioms is the assignment of utility levels or measurements to specific outcomes. If it is assumed that an individual's choices in simple cases obey the axioms then one may infer from these choices the individual's utility levels. These utilities may then be used in more complex cases (12). Similarly, von Neumann and Morgenstern state that the utility of an outcome is equal to the probability of winning a gamble such that an individual is indifferent between accepting the gamble and receiving an outcome with certainty. In other words, an individual may be confronted with two possibilities, A and B, and, in addition, there exists a third possibility, C, which is preferred to B but not to A (i.e. C is preferred to B and A is preferred to C). It is possible under these conditions to find a level of C for which the individual is indifferent between receiving C with absolute certainty or taking a gamble between the two extremes, A and B. It is common to represent such a decision with a following decision tree (Figure 1).

FIGURE 1
Basic Decision Tree



where the box (decision node) represents a choice between C and the A/B gamble and the circle (chance node) represents possible outcomes of a decision. Furthermore, numerical measures can be introduced by assigning probabilities to the two possible outcomes (Figure 2). Again, C can be found for which the individual is indifferent to receiving outcome C or taking the gamble of A with probability, p, and B with probability, 1-p.

Figure 2
Decision Tree with Outcomes and Probabilities



It is often true in utility assessment that the values of A and B are the maximum and minimum (most preferred and least preferred) of a range of possible outcomes. When this is true, A and B are assigned utility values of 1 and 0, respectively, to facilitate the measurement of the utility levels of intermediate outcomes. This can be written as u(A) = 1 and u(B) = 0. The utility value of C, therefore, should fall between these values as would be expected given the preference relationship: B is less preferred than C which is less preferred than A. Using simple algebra and utility theory the value of p (the probability of A occurring) is defined as being equivalent to the utility of C if indifference between the options exists. According to utility theory, A, B, and C can be represented by utilities, and because A has been assigned a value of 1 and B a value of zero, the following equation holds true:

$$u(A)p + u(B)(1-p) = u(C)$$

and simplifies to:

$$p = u(C)$$

where u(C) is the utility of outcome C. Utility, therefore, provides a means of assessing the strength of preference for an outcome relative to other possible outcomes. In fact, it is possible to take any number of intermediate outcomes and assess their individual utility values. Further coverage of the principles of utility theory can be found in a number of works (5,7,8,10,11,13-15).

In summary, it is useful to outline an application which incorporates the theory discussed above. First, the outcomes which are to be assigned utilities must be clearly defined. Next, a scale is constructed which is based on the outcomes of interest. Often this is an arbitrary scale of zero to 1 with the most appealing option assigned the maximum value and the least preferred option the minimum value of zero. A final step may be the elicitation of utilities for the various intermediate outcomes on the specified scale using utility assessment methods. Several of these methods are described in the following section.

UTILITY ASSESSMENT METHODS

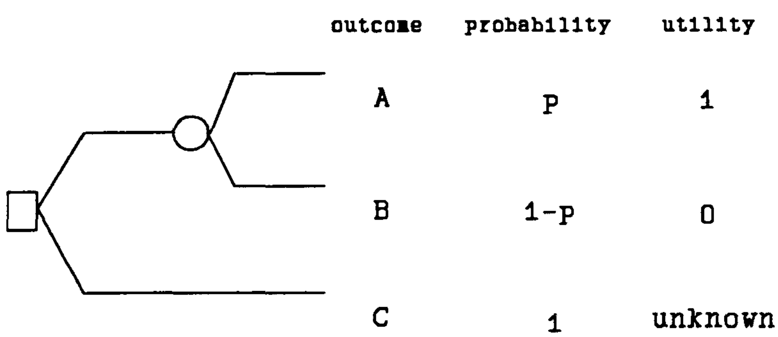
Single-attribute Utility Assessment Methods

Many different methods of directly estimating utility levels exist; some are based on the indifference gambles of uncertainty utility theory, whereas others have been developed as the need for different methods has arisen.

Standard Gamble Methods

The group of methods that is most often used are called standard gamble methods (SG). These techniques are based on the utility theory relationship between various outcomes, outlined in the previous section. The general form of the decision tree as described earlier is shown in Figure 3.

Figure 3
Standard Gamble Decision Tree



According to utility theory the utility of outcome C is equivalent to the probability, p, of the occurrence of outcome A under indifference conditions. In the above relationship there are four possible variables: A, B, C, and p. In utility assessment, three of the four variables are held constant while the final one is varied until indifference exists between the two choices. Consequently, three main types of standard gamble elicitation procedures have been developed.

Certainty Equivalence Method

The first technique is called the certainty equivalence method (CE). This is employed when the outcomes, A, B, C, are continuous variables, such as money or time. It is common in this method to set p at 0.5 (50%), therefore, giving equal probability to A and B in the gamble. A and B are generally the extreme values of the entire possible range of outcomes and C is an intermediate whose value is varied until indifference exists between the options. The outcome value of C is then given a utility of p, or in this case, 0.5. The analyst continues in this manner, but replaces outcome B with C. The 0.5 utility value of the bisection of the C to A outcome range is assessed and can be called D. Using the same equation as before, but replacing B with C:

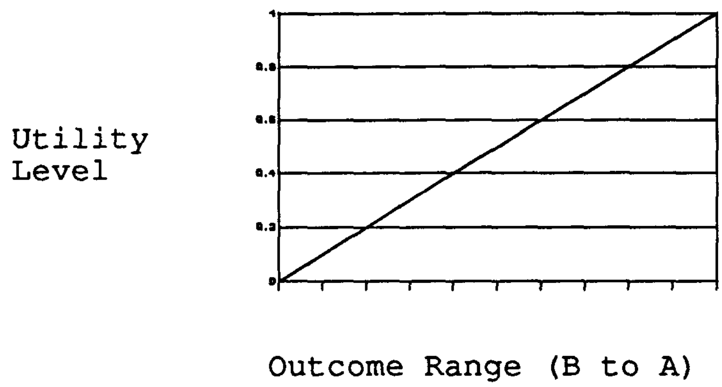
$$u(A)p + u(C)(1-p) = u(D)$$

The utility of A, u(A), has already been set at 1, u(C) has been previously assessed at 0.5, and the probability remains at 0.5, therefore:

$$u(D) = 0.75$$

On the overall utility scale between B (0) and A (1) this second assessed point, therefore, has a utility of 0.75. The analyst continues this process, assessing as many bisecting utilities as is desired until a smooth utility function is determined. The utility function or curve is commonly represented by a graph of utility on the y-axis (0 - 1) and outcomes on the x-axis (B - A). This provides a graphical representation for all outcomes within the range of B to A.

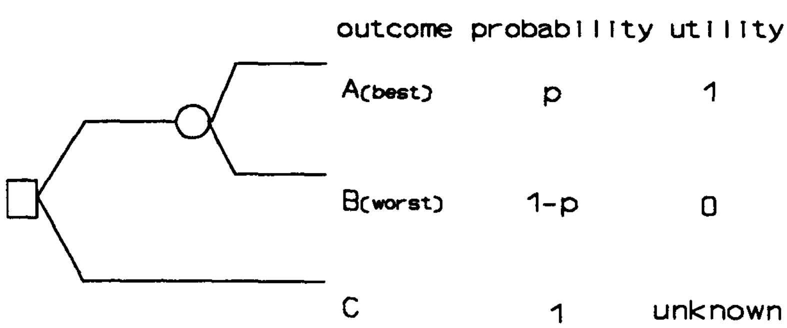
Figure 4
Basic Utility Curve



Probability Equivalence Method

In some cases the outcomes are discrete, such as objects or health states. In these cases a different method must be used. This second technique is called the probability equivalence method (PE). In this method, the analyst sets A and B as the most and least preferable options, respectively, and selects and intermediate option C. This is represented in Figure 5.

Figure 5
Probability Equivalence Decision Tree

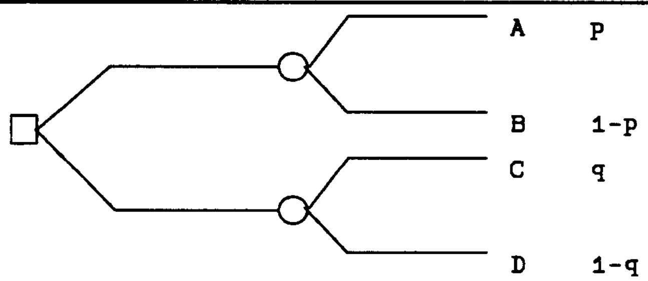


The value of p is varied until the decision maker is indifferent between the certain outcome C and the gamble over A and B. This method may also be used when the outcomes are continuous and is often used as a consistency check for the CE method. Just as before the utility of C is equivalent to the elicited probability, p, and a utility curve for the various discrete outcomes between A and B is drawn.

Value Equivalence Method

A third method of standard gamble techniques is the value equivalence method (VE). In this technique the values of B, C, and p are held constant and A is varied. This method, however, is rarely used in the literature and will not be discussed further. There are also equivalent versions of the PE and VE methods which involve the comparison of two gambles (Figure 6)

Figure 6
Gamble Comparison Decision Tree



These are also not popularly used because it often believed that many people have difficulty comparing gambles. Further information is available concerning standard gamble methods (5,8,10,11,13,16).

Utility Curves

In using each of these standard gamble methods it is possible to create a utility curve. A number of points should be made, however, concerning the shape of the resulting curve. If, for example, the midpoint of the outcome range is given a utility value of 0.5 the individual is said to be risk neutral. A series of such risk neutral utility elicitations would result in a linear utility curve from (B,0), the origin, to the point (A,1). Similarly, if the intermediate outcomes are given utility values greater than those expected from risk neutrality then the resulting curve will be concave downward and the decision maker is said to be risk averse. Conversely, if the curve is convex downward then the decision maker is said to be risk seeking. These types of risk attitudes are shown graphically in Figures 7 and 8.

Figure 7
Utility Curve Representing
Risk Seeking Behavior

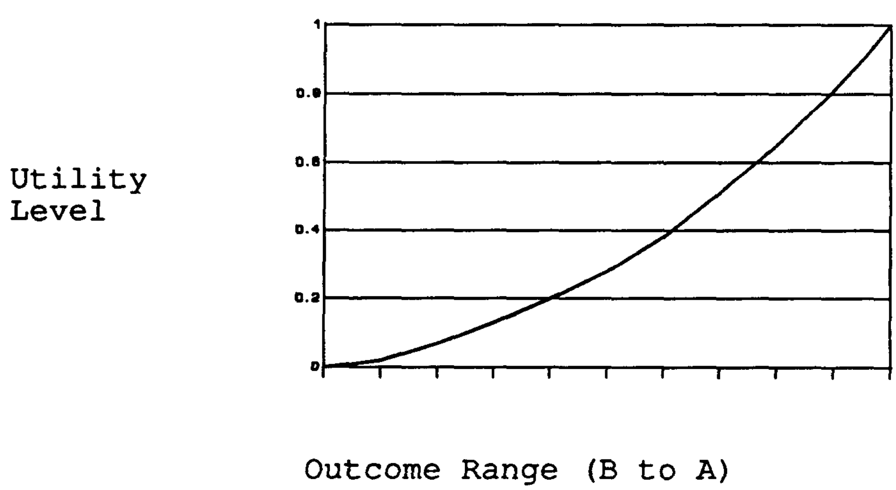
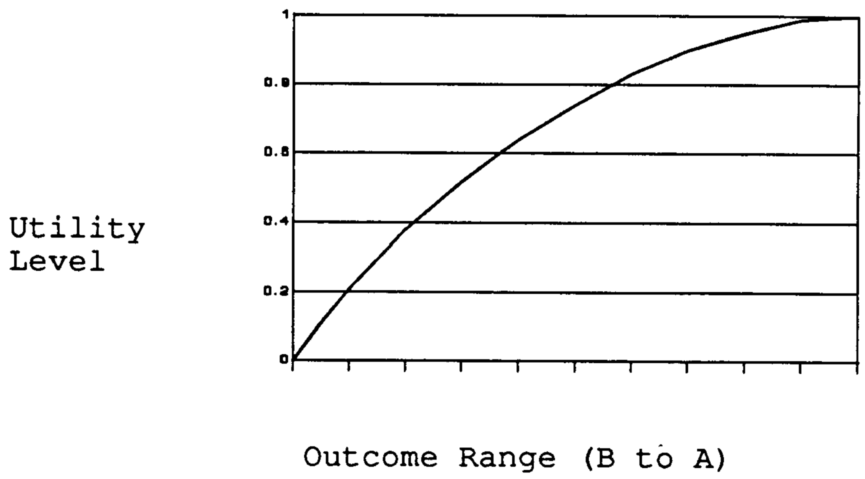


Figure 8
Utility Curve Representing
Risk Averse Behavior



Category Scaling Method

A second type of single attribute utility assessment method is category scaling (CS). This technique generally involves the use of a visual analogue or "feeling thermometer". First, the individual ranks the outcomes from worst to best. The worst is given a value of zero and the best a value of 1. The remaining outcomes are rated, relative to the extremes, on the visual scale. Torrance (17), for example, suggests a 100 unit scale, 10 cm in length. In addition, small arrows are provided to the individual to be used as indicators to identify his relative positioning of outcomes on the scale. Further explanation and discussion on the use of category scaling is provided by (18-23). Some studies have shown that category scaling is best for obtaining ordinal rankings only and should not be employed to elicit cardinal utility values (22,23) and is not grounded in the principles of von Neumann-Morgenstern utility theory.

<u>Multiattribute Utility Assessment Methods</u>

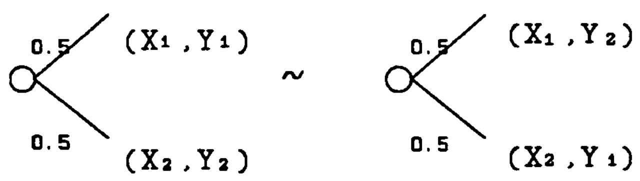
In the example of single attribute analyses the outcomes (A,B,C) are each at different levels of one attribute, and are compared, therefore, on a single utility scale. In many cases, however, an outcome will have several different attributes associated with it, each at a different level. When faced with comparing such outcomes with multiple value dimensions, difficulty may arise because of the presence of conflicting goals. The best possible option may involve maximizing one attribute while minimizing another. In such instances the application of multiattribute utility theory (MAUT) may be employed for the comparison or valuing of outcomes. Basically, the outcome being valued must be broken down into its component parts - the different single attributes. Each individual attribute may then be assessed as described previously. A model to reaggregate the single attribute utility functions, which generally includes weights or scaling factors that also must be assessed, is necessary.

There are three main types of aggregation models: additive, multiplicative, and multilinear. Each is progressively more complex but requires a less restrictive independence condition than the previous one. Associated with each model is a utility independence condition that must be met for the model to be applicable. The three types of independence conditions are called: additive independence, mutual utility independence, and order-one utility independence. They correspond, respectively, to the three models listed above.

Additive Model

The additive model is the easiest to use but its additive independence restriction is the most difficult to meet. For every attribute, x_j, additive independence must hold between it and all other attributes (y, z, etc). Additive independence holds if changing the values of one attribute does not alter the preference for the attribute being assessed. For example, in a two attribute system, where x and y are the attributes, the individual must be indifferent between the following pair of choices shown in Figure 9 if each branch has an equal probability of occurrence.

Figure 9
Requirement for Additive Independence



where x_j and y_j are different levels of attributes x and y. Changing the value of attribute y should have no effect on preferences for attribute x.

Once additive independence is found to exist between all attributes or groups of attributes, the additive model may then be applied.

The form of the model is quite simple, but requires a lot of time to assess.

$$U(X)=\sum_{j=1}^{n} k_j u_j(x_j)$$

where,

$U(X)$	= the multiattribute utility
k_j	= weight or scaling factor
$u_j(x_j)$	= utility of level x of attribute j
n	= number of attributes

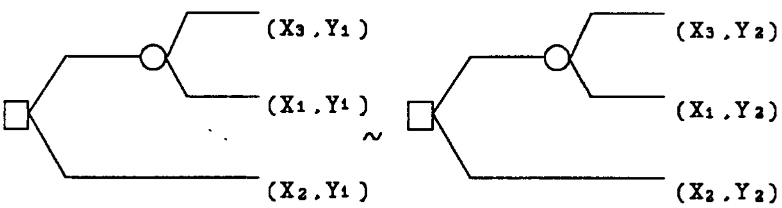
and,

$$\sum_{j=1}^{n} k_j=1$$

Multiplicative Model

To use the multiplicative model of utility aggregation, mutual utility independence must hold. Mutual utility independence exists when preferences for uncertain choices involving different levels of attribute x are independent of the level of attribute y. For example, if x_1 is a minimum value, x_3 is the maximum, and x_2 is an intermediate value then the indifference (~) relationship shown in Figure 10 must hold for utility independence to exist in this two attribute system:

Figure 10
Requirement for Mutual Utility Independence



For more than two attributes, mutual utility independence holds if there is "no interaction between preferences for lotteries on some attribute and the fixed level on the other attributes"(11). If this condition is met, the following multiplicative model equation can be used:

$$1+kU(x)=\prod_{j=1}^{n}[1+kk_j u_j(x_j)]$$

where,

U(X)	=	the multiattribute utility
$u_j(x_j)$	=	utility of level x of attribute j
n	=	number of attributes

and,

k and k_j are scaling factors where
k_j is a scaling factor that makes single attribute assessments consistent with overall assessment, and
k is a scaling factor that is a solution to:

$$1+k=\prod_{j=1}^{n}[1+kk_j]$$

Multilinear Model

The third model type is called multilinear. It is the most complicated to use, but requires the least restrictive independence condition, order-one utility independence. This is simply met by insuring that each single attribute is independent of all other attributes (i.e. pairs or groups of attributes need not be independent of remaining attributes). The multilinear model is superficially similar to the multiplicative model, but has a series of interaction parameters, k. In most cases, however, the multilinear model is complicated and one study has shown that generally the simplest model, the additive, is sufficient (24). This, of course, cannot be accepted as a general rule.

Assessing Independence and MAU Functions

For each of the three models discussed above the method for assessing the multiattribute utility function is quite similar. First, the single attribute utility functions for each of the attributes are assessed using single attribute methods. Next, the k_js are assessed by eliciting the utility of setting one attribute at its best level while the others are at their worst. For example, in a three attribute system:

$$k_1 = u[x_1(b), x_2(w), x_3(w)]$$
$$k_2 = u[x_1(w), x_2(b), x_3(w)]$$
$$k_3 = u[x_1(w), x_2(w), x_3(b)]$$

where,

$x_j(b)$ = best possible level of attribute j

$x_j(w)$ = worst possible level of attribute j

Finally, when using the multiplicative and the multilinear models, the scaling constants, k_i, are calculated iteratively. In addition, Klein et al. (25) have developed a method of assessing multiattribute utility models with mathematical programming.

It is also necessary to demonstrate that the specific independence condition holds for the model being used. Because it is very difficult and time consuming to demonstrate additive or mutual utility independence, Keeney and Raiffa (5) have developed a number of simpler methods to demonstrate independence. Torrance (17) also outlines some of these. For example, Torrance states that additive independence can be determined by first demonstrating that mutual utility independence exists. It is then necessary to establish additive independence for only any two attributes with all other attributes held constant. Similarly, the demonstration of mutual utility independence can be simplified by showing that utility independence, as described above, holds between one attribute and the others, and then showing that the remaining pairs of attributes which involve the one tested for utility independence are preferentially independent. Preferential independence exists when an individual is indifferent to outcomes involving one or more attributes regardless of the level of the remaining attributes. In a three attribute system, for example, with x_1, x_2, and x_3 as attributes, mutual utility independence can be shown by demonstrating the following:

(x_1) is utility independent of (x_2,x_3)
(x_1,x_2) is preferentially independent of (x_3)
(x_1,x_3) is preferentially independent of (x_2)

UTILITY ASSESSMENT of HEALTH OUTCOMES

The basic concepts and methods of utility theory remain unchanged when applied to the field of health; however, it has been necessary in some cases for new or slightly altered methods to be employed. These changes are generally considered valid if the axioms of utility theory still hold. In fact, Torrance (26) restates the axioms to fit in the context of health states and comments on their validity. He states that the axiom of continuity has been empirically tested and appears to be applicable while the others seem to be reasonable, but none has been rigorously tested.

The use of uncertainty utility theory in the health field has grown dramatically in the past two decades. Many of the medical applications of single and multiattribute utility analysis prior to 1980 are reviewed by Krischer (27). Since that time the use of utility and its traditional methods has continued to expand and new methods have been created.

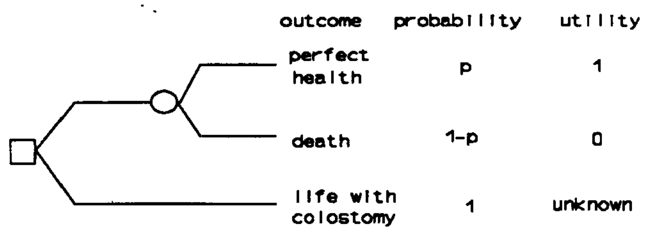
Single-attribute Approaches to Health Status Assessment

Single attribute utility analysis has been used significantly to assign values to health states for the purpose of clinical, technological, and health program decision making. Also, it has been widely used in the creation of health indexes as a way of prioritizing health states. There are many examples of such uses in the literature. Utility values have been assessed for various types of cancer including ovarian (28), gastric (29), rectal (30), laryngeal (31), endometrial (32), lung (33,34), and various other cancer states (35,36). It has also been used with such chronic conditions as prostatic hypertrophy (37), Hodgkin's lymphoma (38), arthritis (39,40), kidney disease (41), osteoporosis (32), and generally poor health or disability (41-43). It has also been applied to other areas including outcomes from coronary artery bypass surgery (23), menopausal symptoms (32), childbirth (44), genetic counseling (45-47) and drug effects (48,49).

In most of these cases, an expert, physician, or patient was asked to rate these conditions on a single attribute utility scale of quality-of-life using one of the elicitation methods described earlier. For example, category scaling was employed by Llewellyn-Thomas et al (31) when they asked subjects to indicate on a 100 mm line the relative desirability of several health state scenarios. Similarly, Boyd et al. (30) utilized a standard gamble method to elicit the value of living with colostomy. Various groups of subjects were presented with the choice between two alternatives: A - living a full lifetime with a colostomy (certain outcome) or B - taking a gamble of perfect health for a lifetime with probability p or immediate death with probability 1-p. The value for p was elicited from the subjects until there was indifference between the choices, A and B.

This is represented schematically in Figure 11.

Figure 11
Decision Tree with Health Outcomes



This is equivalent to the PE method described earlier. In examples such as this the CE method cannot be used because it requires a continuous variable, whereas the PE method can accommodate discrete values such as health states.

Multiattribute Approaches to Health Status Assessment

Single-attribute utility assessment has been used significantly in the health field; however, some groups have found it necessary to decompose quality-of-life into several attributes. Consequently, in assessing a subject's utility function for the quality-of-life in a health state, a multiattribute utility (MAU) model must be used. An excellent review of the application MAU theory to health state evaluation is found in (50). Torrance et al. (51) have created a four attribute classification system to categorize various levels of health. The four attributes each represent a different facet of health which must be considered in determining value. In their opinion, the value of health states depends upon: (1) physical function (mobility and physical activity); (2) role function (self care and role activity); (3) social-emotional function (emotional well-being and social activity); and (4) health problems. As is done in traditional MAU analysis, each of the utility functions for these attributes must be assessed individually and then aggregated using one of the models.

Keeney and Ozernoy (6) employed an additive multiattribute model to assess the relative values of the possible health impacts of several carbon monoxide (CO) standards. Judgments about the utility function and scaling factors for four attributes were elicited from an EPA staff person. These attributes concerned four possible health effects of CO exposure: heart attacks, angina attacks, peripheral vascular attacks, and vigilance impairment.

The MAU method has also been used in the creation of health status indices (52). Gustafson et al. (53) have used the additive model to develop a severity index. In this case the attributes are various indicators of the severity of heart disease. Similarly, Gustafson's model has been applied by Choi et al. (54) to assess the severity of non-traumatic chest pain.

Other methods of valuing health effects have been developed, such as the index of well-being (55). This index is based on an ordinal ranking of various health states from which scores similar to utility are derived.

Incorporating Health State Quality and Duration

In both the single and multiattribute methods described above the main purpose was to value specific health states independent of any other factors. It has been suggested by Dowie (56), however, that this may not be an accurate representation. He argues that it is not appropriate to value life and health directly, but instead each should be seen as a demand for time (i.e. nothing is consumed independent of time). Dowie suggests, therefore, that it is time that should be valued (in terms of utility).

Single Attribute Approaches

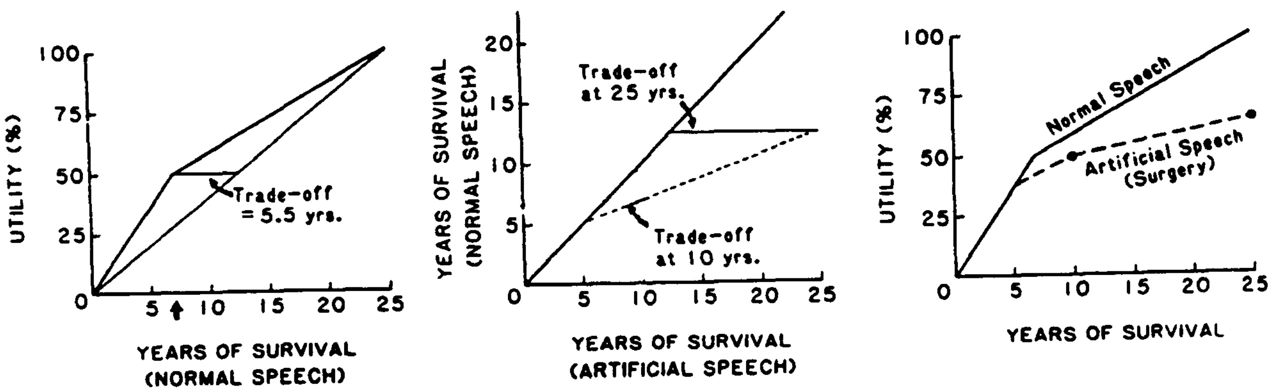
Torrance (57) also felt that incorporating time was important and devised the single attribute time trade-off method (TTO) which evaluates the value of health states in the context of time. This method has been used extensively and was developed specifically for health outcomes. The technique was created because many people have difficulty understanding and working with probabilities. The method is not based on von Neumann-Morgenstern utility axioms and requires an additional assumption that the subject's utility function for additional healthy years be linear over time (39). This assumption has been a serious point of controversy.

In the TTO method the subject is provided with two alternatives. The first alternative is living the rest of one's lifetime (t) in a specified health state, such as arthritis. The second alternative is living in perfect health but for a shorter period of time (x). The number of years of perfect health are varied until the subject is indifferent between the two alternatives. The preference or utility value is defined then as x/t. This method has been used and described by Torrance and other researchers (21,22,29,37,38,40,57-60). For example, Krumins et al. (37) used the TTO method to value the possible outcome of prostate surgery. In a situation such as this, TTO is very good because patients and physicians must often try to balance between quality of life and prospects for survival.

The balancing of the duration and quality of life is a common goal in the health field. In fact, a unit of measurement has been devised which incorporates these two values and has been called quality-adjusted life years (QALY). QALY is basically a measure of expected time of survival adjusted for varying states of health. For example, living ten years with a disability or disease is worth only a fraction of living ten years in good health. QALYs provide a means, therefore, of comparing survival in two states of health. A review of QALYs is presented in (60,61).

QALYs are not necessarily used when time and quality are being accounted for. For example, McNeil et al. (62) studied the differences in the utility of survival with artificial and normal speech. First, the CE method was used to determine a utility curve for duration of survival. In the next step the TTO method was employed to create a graph of years of survival with normal speech (y-axis) and years of survival with artificial speech (x-axis). If the two were valued equally then a linear relationship with a slope of 1 would result. In this manner utility values for varying years with artificial speech were determined based on the CE and TTO utility curves. Consequently, two curves were drawn which compared the utility for years of life in each of these two states. The effect of a poorer health state over time, therefore, could be observed graphically. The curves produced by this method are shown in Figure 12 (62). This procedure, however, does not produce the QALY measure that is often desired.

Figure 12
Utility Curve Construction for Survival with Artificial Speech



Note: above graphs taken fron reference (62)

When such a measure is required the utility level for a specific health state is multiplied by the average duration of the health state to get QALYs. Utility measures for health states derived from TTO, SG, or CS methods may be used for calculating QALYs but only the TTO method considers quality in the context of time. This simple single attribute method of is used only to obtain weights and does not fully incorporate preferences for time (63). This controversy is discussed later in this report.

Multiattribute Approaches

In an attempt to compensate for the weaknesses of the single attribute approach to quality of life and health status duration incorporation, a number of different models have been developed to calculate functional equivalents to QALYs using multiattribute utility (MAU) or MAU-like methods. Pliskin et al. (64,65) developed a MAU model for this purpose which is based on several assumptions. First, it is assumed that mutual utility independence exists between survival time and health status. The resulting model they use is a "quasi-additive" form of a MAU function:

$$U(Y,Q) = au(Y) + bu(Q) + (1-a-b)u(Y)u(Q)$$

where,

$u(Y)$ = utility for survival time
$u(Q)$ = utility for health status
and a and b are weights.

It is also assumed that "constant proportional tradeoff" is valid. This means that an individual is willing to give up the same proportion of his remaining life for an improvement in health regardless of how many years remain in his lifetime. For example, if an individual is willing to give up 3 of 15 remaining years of expected lifetime for an improvement in health, then he must also be willing to give up 4 of 20 remaining years for the same improvement.

The second assumption implies that the utility function, U(Y,Q), exhibits constant proportional risk aversion. It will, according to Pliskin et al., therefore, take one of three general forms (concave, convex, or linear) of which the linear form is selected. Miyamoto and Eraker (66) develop further this model and state the following relationship between the QALY-like measure, U(Y,Q), and a bivariate utility function:

$$U(Y,Q) = bY^{r}H(Q)$$

where,

Y = survival time
H(Q) = utility of survival in a health state, Q
b = scaling constant
r = risk attitude factor with respect to survival duration

Using the PE or the CE method the value for r is determined and the TTO method is employed to determine the utility function for health status, H(Q). Extensive examples and proofs are provided in (64-66).

Loomes and McKenzie (67) criticize this method for determining QALYs. They first attack the constant proportional time trade-off assumption on the grounds of empirical evidence from (41,43,62), which show that individual's preferences change depending on the expected time in the health state. Furthermore, the above model does not account for individual preference for present consumption over future consumption; this is called time preference (68). Loomes and McKenzie (67) suggest alternative methods that do not involve traditional utility analysis.

Other Methods

Other alternatives to QALYs have been suggested in response to criticisms of QALYs (63,67,69-71). One of these alternatives to QALYs is Healthy-Years Equivalents (HYE), suggested by Mehrez and Gafni (63). HYEs cannot be assumed to be equivalent to QALYs and Mehrez and Gafni warn that it may not be possible to construct conversion curves. They support HYEs because even though they are more difficult to elicit, they include preferences for both time and quality of survival. In addition, they provide several examples where QALYs would incorrectly describe a subject's true preferences and they provide a full description of the method for eliciting HYEs in the appendix of (63).

A final method that should be mentioned briefly is the DEALE method (Declining exponential approximation of life expectancy). Several groups have used this method to assess what they call utilities (72-78). This method assumes that life expectancy can be approximated by a simple exponential function. Therefore, survival is calculated using the reciprocal of the age, sex, and race specific mortality rate combined with the reciprocal of the rate of disease in question. Quality adjustments for long and short term morbidity are then made to the calculated life expectancy. This value is used as a "utility". The result is a measure of quality adjusted life expectancy.

COMMENTS ON UTILITY ASSESSMENT AND QUALYs

As mentioned above, both utility assessment and QALYs are often criticized for various reasons. Included in these criticisms are general comments concerning decision analysis overall, perception, and the psychology behind stating preferences (79-81). In the following section, the specific criticisms concerning utility analysis and QALYs are discussed.

Utility Assessment

The advantages and disadvantages of utility assessment are frequently enumerated. There appear to be some points that are repeatedly stressed. For example, Albert (3) comments that "utility functions for one individual cannot be carried over to another individual or group" while Kassirer (82) states the opposite, but qualifies it by saying that comparing utilities is only acceptable in a non-rigorous analysis. Furthermore, Albert states that utilities cannot be associated with a monetary amount because different individuals have differing utilities for money. Feeny and Torrance (39), however, clearly state that an advantage of utilities is their ability to be integrated into economic evaluations.

Other pros and cons of utility assessment have been stressed by a number of authors (39,83,84). Utility can be a very comprehensive measure, taking into account all the many attributes and tradeoffs presented by a problem and aggregating them on one scale. Furthermore, various evaluators or raters can be elicited. These may include experts, patients, policy makers, or even the general public. There has been some discussion as to whether an individual can truly give a value (or disvalue) to something he has not experienced. Drummond (84) states that the issue of "whose values" may depend upon the purpose of the study, as some have stated (58,83), but says that further investigation is required. If such a variability in raters can exist it allows utility assessments to be applied to hypothetical situations which greatly increases the applicability of the method. Finally, utility can be combined with outcome probabilities to get expected utilities with which comparisons with other possible outcomes can be made.

The advantages are, of course, balanced by a number of disadvantages. There is complaint of a lack of precision in that the same rater's utility levels may change greatly from one measurement to the next. In addition, the elicitation process consumes a lot of time and labor, and requires trained professionals to attain the best results. It is also common to find that the results of utility studies are not easily interpretable, and there have even been suggestions that the method of decomposing a problem as utility analysis does, may change an individual's preferences (28).

Sources of Bias in Utility Assessment

When performing a specific study there are significant sources of bias or error which may greatly affect the results.

There have been quite a few studies which have pointed to the fact that significant differences may result from the various methods of utility elicitation. Again, this is a source of controversy and there are studies which support both sides (14,19,53,80-88).

Much of the discussion in the literature on the comparability of assessment methods concerns the three methods: SG,CS, and TTO. Read et al. (23) found that the three methods produce significantly different results, with SG resulting in the highest utility and CS, the lowest. Large differences between CS and SG were also noted in (18,89,90). In one of these studies, however, Torrance did not find statistical differences between SG and TTO (89). Wolfson et al (18) found that TTO results were close to those found using CS. Conversely, the SG method has been shown to agree with direct evaluation (CS) results (55,91).

Other comparisons have been made between the different types of SG methods. For example, Hershey et al. (12,92) cite several studies that show differences in the shape of utility curves created by CE and PE methods. CE resulted in more risk seeking behavior and PE resulted in aversion to risk.

The ability to point out differences between methodological results, however, does not provide judgment of which method is best. Economists generally support the use of SG techniques because they have the strongest foundation in utility theory axioms (21,23) and they involve risk. Psychologists and regulators argue, however, that visual scales are superior because of their ease of use and because risk is not always a factor in a decision. These strong preferences for specific methods and the obvious differences in results from these methods may restrict the use of certain methods to specific areas or studies. In an attempt to explain some of the discrepancies and provide assistance in selecting a method, much work has been done on the psychology of utility assessment and the factors that affect decision making abilities.

One area that has received significant attention is the effect of time on an individual's utility values (21,31,34,41,43,68,93). Time preference is very important because of its potential effects on utility values. Time preference is the desire for gains at the present as opposed to equal gains at some point in the future. Some utility assessment methods assume that time preference does not exist. This is not supported by empirical studies (21,34,68); however, there are methods of accounting for or measuring time preference. Most commonly, the CE standard gamble method is employed. Using this technique the utility of varying years of survival can be measured.

Utilities have also been shown to be affected by the length of time that an individual is in a specific health state. As the length of time increases, the utility for being in that health state decreases (31,41,93). Furthermore, it has been found that in very disabling states, individuals often reach a point of "maximum endurable time" after which death becomes more preferable (43).

Another factor that has been investigated for its effects on utility is personal position or context. Christensen-Szalanski has shown that utilities of women in childbirth change with regard to preferences for anesthesia (44). It has not been proven, however, that age, sex, social position, or professional status have any effect on the utility values elicited for specific health states (36,41).

It has also been shown that individuals in specific health states value the health state differently than objective observers or medical experts (30,41). The question arises, therefore, of which group of people should be used to elicit utility levels. Studies have been done which employed medical experts (18,23), patients (18,35,41,42,94), and objective raters (41,55,95). It can be argued that "the choice of raters should be influenced by who are the stakeholders" (83), but it can also be argued whether these "stakeholding" raters can really provide an informed judgment. Many opinions exist on this question, but there may be no right or wrong answer. This topic, however, must still be considered when conducting a utility assessment.

A final area that has received significant attention is the psychology behind the assessment of utilities. It is often believed that individuals allow biases to affect their decision making (79), therefore, it should be no different in the assessment of utilities. Extensive work in this area has exposed a number of psychological factors that affect the valuing of outcomes. The factors include framing, regret, outcome bias, and range and probability effects among others. The factor that receives the most attention is framing or context bias (33,36,92,93,95-98). This type of bias can be controlled by the analyst because it is caused by the way in which questions or elicitations are posed to the subject. For example, Llewellyn-Thomas et al. (97) have shown that the form of the health state description affects utility values being elicited. They found that assessed utilities for health states described in the first person narrative form were significantly different from utilities assessed for the same condition described in standard point form. Furthermore, the tone of the health state description, whether it is framed in positive or negative terms, can affect the outcome (33,36). Regret (12,32,92,93) is the tendency to shy away from or devalue outcomes that could cause the decision maker to regret making a wrong decision. This is especially common in the field of medical decision making where physicians must value possible outcomes or treatment options. For example, treatments or therapies that have some potential for disabling effects may be devalued because of regret bias even though they may be highly unlikely. Outcome bias refers to the shifting of risk attitude (risk aversion or risk seeking) depending on the whether the outcome is a pure loss, pure gain or mixed situation (49,92,96). The range of the outcomes has also been shown to affect the assessment of health state utilities. Sutherland et al. (42)

found differences in utility values depending on whether perfect health and death were used as anchors or a smaller range including an intermediate effect and perfect health were used. Others have also described the occurrence of this bias (87,94,96).

Other biases which have been identified include aversion to gambles over health outcomes (89), the spreading of responses across entire utility scales (23) (especially with CS technique); the overweighting of low probability events (32,79,92); thinking in only one dimension (i.e. not including all attributes) (92); and overweighting the value of past events because they are easily recalled or remembered (23,96). There are, of course, many other sources of error or bias and not all those listed above apply in all situations. Each one, however, should be considered and accounted for, if possible, during any elicitation process.

Quality Adjusted Life Years (QALYs)

The use of QALYs as a decision making tool has increased significantly during the past decade; consequently, so have the criticisms of this method of measurement. As stated earlier, QALYs have been attacked because of the restrictive assumptions (67): utility independence, risk neutrality for time, and constant proportion trade-off; and because of their simplicity: utility used only as a quality weight for life years (63). Several authors have brought up ethical questions in addition to the problems with validity. They have even gone as far as stating that QALYs are unjust (69-71). They complain that QALYs value time over individual lives, too narrowly define the meaning of quality of life, and do not treat all age groups equally. Conversely, equally strong arguments are made in support of QALYs (100-103). These authors argue that even though some problems may exist with QALYs, they are usually successful in their goal of comparing specific health states or treatment programs. More time, they state, should be spent on standardizing the methods and measuring sensitivity.

ASTHMA AS A HEALTH STATE OF CONCERN

Many varied diseases and physical conditions have been the object of research using the utility under uncertainty techniques. One health state, however, which apparently has not been addressed in this manner is asthma. Asthma is a condition that may be characterized by many different attributes, therefore, it should lend itself to the use of utility assessment methods. Furthermore, the valuing of these various attributes by asthmatics should be given some importance considering the significance of asthmatics in air pollution research and standard setting.

Definition of Asthma

Asthma, in its many and varied forms, is a condition that affects at one time or another approximately 20 million individuals in the United States and accounts for over 6 million doctors visits, nearly 2 million emergency room visits, and 1 million work days lost in a single year (104). Often assumed to be a specific disease, the term asthma, in fact, "encompasses many patterns of response to a variety of stimuli, which find common expression in variable airflow obstruction" (105).

Many attempts have been made to formulate an accurate and all-encompassing definition for this disease, yet discussion and controversy concerning the true description of asthma have continued for decades. A frequently accepted definition is that of the American Thoracic Society (1962) which states that asthma is a "disease characterized by an increased responsiveness of the trachea and bronchi to a variety of stimuli and manifested by narrowing of the airways that changes in severity either spontaneously or as a result of therapy" (106). This definition was rejected by a study group in 1971 because it allegedly was not a definition of a "disease". Furthermore, in 1980, Gross, following the philosophy of Karl Popper, suggested that asthma should remain undefined (107).

Because of the lack of agreement over a specific definition it may be useful, instead, to provide a simple broad definition, but include defining characteristics in an explanatory paragraph. Scadding does just this by defining asthma as "a disease characterized by wide variations over short periods of time in resistance to flow in the airways of the lungs" (108). To this definition one may add various symptoms and causes to better characterize the disease. For example, the airways of asthmatics are often referred to as being hypersensitive to various stimuli or environmental factors in concentrations that would not be expected to affect non-asthmatics. The disease may also be episodic or persistent and may or may not be associated with atopy, an Immunoglobulin-E (IgE) mediated allergic response. IgE refers to a specific antibody that reacts to inhaled allergens. Furthermore, the symptoms may be augmented by the swelling of airway tissue or the collection of mucus in addition to the constricting of the smooth muscle of the air pathways.

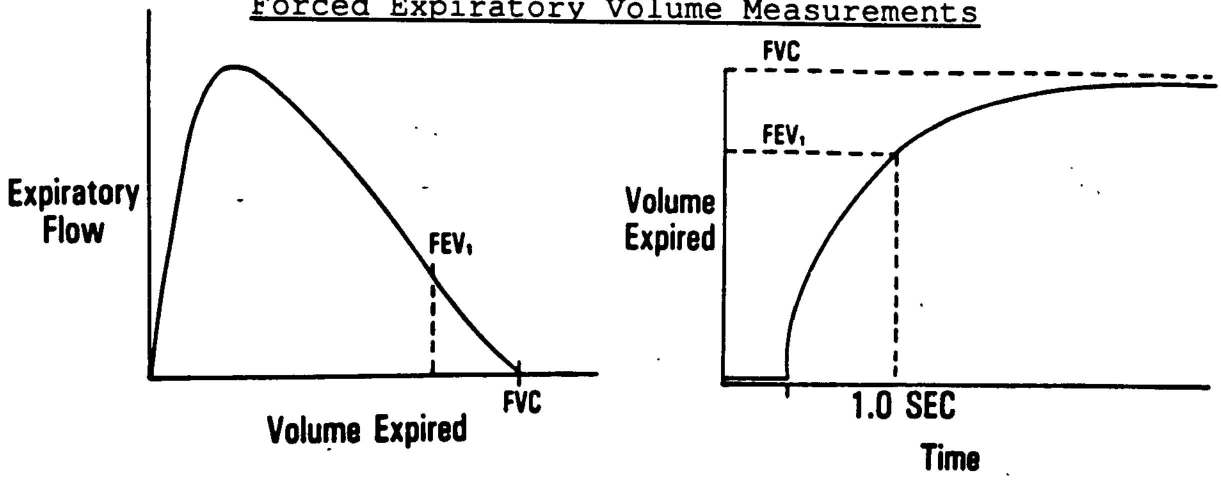
The causes for the narrowing of the airways is somewhat unclear. It appears, however, that asthmatics are genetically predisposed and that various humoral, neurogenic, and environmental factors exaggerate the effect (109). These include such physical, chemical, pharmacological, and immunological stimuli as allergens, infectious agents, cold air, exercise, emotional stress, laughter, inhaled substances such as methacholine and histamine, and atmospheric pollution. It is this latter one that is of particular interest to regulators and environmental scientists. Many studies have been performed on the effects of air pollutants on the lung function of asthmatics; several of these will be discussed later in this report.

Asthma Severity Measurement

The broad definition and many variations of asthma have led to several attempts at categorizing asthmatics. Dawson and Simon (109), for example, divide asthmatics into several groups including those that have no bronchial obstruction but react abnormally to inhalation challenge testing with stimuli, individuals who are acutely episodic, and those that are chronic. Scadding (108) suggests that separate categories should also be made for those whose asthma is and is not affected by inhaled allergens (IgE mediated), and asthmatics whose condition is only brought on by heavy exercise.

A more common method of categorization has been to use some sort of severity scale. In this manner, those that are mildly, moderately, or severely affected can be identified for routine medical and emergency purposes. It has been estimated that a majority of asthmatics are only mildly affected, 25% are moderately affected, and as many as 15% are severely affected (110). Many of the symptoms of asthma, such as airways narrowing, cannot be quantified without the use of clinical measurements. Several of these objective means of measurement have been developed in an attempt to reflect the degree of severity of a patient's asthma. The forced expiratory volume in one second (FEV_1) is the volume of air that an individual can expire in one second. This is a good measure for asthma because the narrowed airways of an asthmatic do not allow for rapid expiration. A second measure is the forced vital capacity (FVC or VC) which is the total volume of air that can be expelled from the lungs. Each of these measures can be used independently or as a ratio FEV_1/FVC. The ratio has the advantage of allowing for better comparison between individuals because it will not be dependent on body size as FVC may be. It is also common to measure the flow rate of expired air using a spirometer and note the peak expiratory flow rate (PEFR). In measuring both the flow and the volume it is helpful to portray the measurements graphically (Figure 13):

Figure 13
Graphical Representation of Peak Expiratory Flow Rate and
Forced Expiratory Volume Measurements



An additional measure that is used is the specific resistance of the airways (SR_{AW}). This value, however, is not as easily attainable because of the need for a body plethysmograph, a complex piece of equipment, and is less reproducible than those described above. Several other measurements exist which are slight variations of those described.

It is often the case that ranges of these measurements are used to indicate the presence of asthma. For example, an FEV_1 to FVC ratio of greater than 0.7 is often considered the normal range. Similarly, a PEFR of 400 - 600 l/min is considered normal, whereas 200 - 400 l/min may indicate the presence of asthma. Bateman et al. (111) proposes bounds that roughly identify healthy or asthmatic individuals. An example is shown below.

	Asthmatic	Healthy
FEV_1 (% predicted)	85 $\pm$ 6	119 $\pm$ 4
FEV_1/FVC	0.74 $\pm$ 0.4	0.88 $\pm$ 0.2
PEFR (% predicted)	76 $\pm$ 5	99 $\pm$ 3

These objective clinical measures used in conjunction with frequency and degree of asthmatic attacks have been used to determine asthma severity in patients. Often these are presented in the form of severity scales. A rather simple scale, commonly called the Aas scale (112), is based primarily on the number and duration of asthmatic episodes in a year, but it also considers drug consumption and clinical evaluation. Godard et al. (113) claim to increase the correlation between severity and this scale by including the objective FEV_1 measurement. Juji et al. (114) attempted to find what measures best correlate with asthma severity. They found that low respiration threshold to acetylcholine, high maximal histidine release by anti-IgE, high serum IgE, and high eosinophil counts in the blood all correspond well with severity. Pereira et al. (115) examined the coefficient of variation (COV) of PEFR in asthmatics. It was found that the COV of PEFR has a bimodal distribution which was interpreted as a natural separation between mild and severe asthmatics. Those individuals with severe asthma had greater variations in their expiatory flow rate than mild or non-asthmatics.

In many cases a more subjective aspect is included in the severity scale. Scadding (108) bases a severity categorization on necessary treatment and lifestyle interferences. Mild asthma, according to Scadding, is controllable with a bronchodilator and there is no interference with normal activities. Moderate severity causes occasional interferences and necessitates the use of systemic corticosteroids, and severe asthma is defined as seriously interfering lifestyle and may include life threatening episodes. Similarly, Jones (116) uses effects to lifestyle and the ability to perform housework or one's job as a part of a severity scale.

A broad and encompassing scale was developed by Brooks et al. (117) to estimate the clinical status of asthmatic subjects. Included were ratings of frequency and degree of four symptoms: cough, wheeze, chest tightness, and shortness of breath. In addition, frequency of attacks and therapy use were considered. Scores were given to various levels within each of these categories to indicate asthma severity. Similarly, Donnelly et al. (118) identified variables which could be used to rate patients severity. In their study multivariate cluster analysis was used to select eight variables which correlated well with severity from a group of 256 seasonal and environmental factors gleaned from patient questionnaires. The selected variables included four symptoms and four lifestyle interferences. The symptoms included cough, chest tightness, wheeze, and shortness of breath, and the lifestyle interferences were hospitalizations, days of school missed, nights of sleep missed, and degree of physical activity tolerated. Several other severity scales have been developed which are also based on degree and frequency of asthmatic attacks and clinical evaluations (119,120).

Often, patients are asked to rate their own severity or subjective feeling about a specific asthma symptom. One commonly used scale was developed by Hackney (121). On this scale, specific symptoms are rated on a scale of zero to 40 on the basis of lifestyle interferences and meication use. Various levels are shown below.

Hackney Scale

0	Symptoms not present
5	Minimal (not noticeable unless asked about)
10	Mild (noticeable but not bothersome)
20	Moderate (bothersome, consider taking medication to alleviate)
30	Severe (interferes with activities)
40	Incapacitating

Other subjective scales have been developed using visual analog scales (VAS) on which various symptoms are rated on a scale of zero to 100 where zero represented no breathing problems and 100 represented total disability. For example, shortness of breath was rated by patients on a VAS scale and the VAS score was then correlated with PEFR measurements. In three studies (122-124) the r values were found to range between -0.7 and -0.85 showing a negative correlation between the two. This implies that individuals who had greater difficulty in breathing and felt more disabled also had lower PEFRs. Similar symptom rating techniques have been used by patients as a part of more encompassing severity scales which also included other criteria such as clinical examination information and drug consumption (125-127).

Air Pollution Effects on Asthamtics

As stated earlier, many diiferent airborne contaminants can adversely effect the functioning of an asthmatic's lungs and may even bring on an attack. There has been a significant amount of research in this area by environmental scientists, especially with regard to air pollutants such as sulfur dioxide and ozone. Regulators are also concerned with the results of such studies because of the need to consider the effects of pollutants on sensitive groups in the ppulation during standard setting. The Environmental Protection Agency (EPA) does just this by reviewing all pertinent studies in order set national ambient air quality standards (NAAQS).

The importance of regulating these pollutants in the atmosphere becomes obvious when one examines reports of severe exposure episodes. In London in 1952 a brief period of SO_2-polluted fog was blamed for hundreds, perhaps thousands of deaths of sensitive individuals. Similarly, 88% of the asthmatic patients in Donora, Pennsylvania experienced exacerbations during a period of high SO_2 concentrations in 1948 (128). These are isolated incidents; however, high SO_2 concentrations have been reported near SO_2 point sources, in indoor air of kerosene-heated homes, and in industrial plants such as paper-pulp mills, smelters, and food processing plants (128).

Sulfur dioxide (SO_2) is one such atmospheric pollutant which has received significant attention. EPA, in an assessment of available health SO_2 health effects data (129) states that asthmatics as a group are more sensitive to SO_2 than non-asthmatic individuals. Furthermore they state that moderate to heavy execise with exposure to SO_2 is likely to cause bronchoconstriction within 5 minute at concentrations of less than 1 ppm. These assertions are based on the results of various inhalation studies which measured several objective, clinical lung function criteria including SR_{AW}, FEV_1, and PEFR as a means of quantifying the observed decreased lung function and bronchoconstriction (130-133).

Similarly, studies on the inhalation of ozone (O_3) by asthmatics were reviewed by EPA during an assessment of effects on sensitive individuals (134). Recent studies were pointed out as reporting airway resistance after O_3 exposure (135-136). EPA concluded that the lungs and airways of asthmatics are more responsive to O_3 than are those of normal subjects.

SUGGESTED PILOT STUDIES

The final part of this project is the design of a number of pilot studies that apply utility under uncertainty techniques to the valuing of asthma health states associated with air pollution. Specifically, three pilot studies have been developed to accomplish two main objectives. The first is to evaluate the possible uses of utility assessment for common problems faced by the EPA. The second is to collect subjective data about how asthmatics value (or disvalue) asthma and its associated symptoms. These two main areas are discussed individually in the following sections.

Evaluation of Utility Assessment

Utility assessment has been shown to be useful in many different fields and even as a possible application to environmental standard setting procedures (6). To further the study of the applicability and ease of use in areas such as this, three pilot studies have been designed to test several methodological variables (which I will call "utility assessment variables") that may affect the results of such tests. Three variables in particular have been selected: subject group, elicitation method, and elicitation format, and each is elaborated upon below.

Subject Group

As mentioned earlier there is much debate about what group should be the decision makers in a utility assessment problem. Some have said that it should be the stakeholders that should be elicited, while others think that the general public or regulators should also have a say. It would be interesting, therefore, to compare the results of studies using one or the other of these general groups. The questions being pursued in this report concern the elicitation of various uncertainty utility levels of asthma and its symptoms. Severe asthmatics are used in the present studies as the stakeholders and non-asthmatics familiar with utility assessment as the other group. This provides a good basis of comparison as to which is more important, to experience a health state first hand or to be knowledgeable about the assessment techniques.

Elicitation Method

There are several types of elicitation methods that are used commonly in the literature. Two of these, the standard gamble method and the time trade-off technique, however, receive much of the attention and appear to have been well accepted. The purpose of the pilot tests is not to compare the results from each method quantitatively but more to weigh their individual advantages and disadvantages. For example, the ease with which subjects can comprehend the technique or the difficulty for the interviewer in performing the elicitation would provide valuable information for later studies.

Elicitation Format

There has been much discussion in the literature concerning biases or errors that may be associated with the format of the study. The pilot studies attempt to test two different format methods: interview and questionnaire. It is expected that a well designed interview should provide more valid results than a questionnaire. For an agency such as the EPA, however, where time and money are often important criteria, it may be helpful to know whether a questionnaire format is a possible option and what limitations may be associated with it.

Subjective Information on Asthma

The second area of interest is information on how various aspects of asthma are judged (i.e., the utility of changes in a health state which may be brought on by exposure to air pollution). From discussions with members of EPA who are associated with the study of asthma and air pollution it appears that there are several areas of primary interest concerning asthma and subjective judgment. These include the severity of asthma, the severity of its symptoms, and the frequency of asthma attacks. Each of these health state variables may be adversely affected by exposure to air pollutants, therefore, subjective judgment concerning them may prove valuable.

Asthma Severity

There is much discussion in the literature about the severity of asthma and the various methods of placing asthmatics in such levels. It may be useful, therefore, to elicit uncertainty utility curves for changes in severity which may be expected to occur upon exposure to air pollutants. For example, this could quantify the difference in effects between mild and moderate (or severe) asthmatics. Or, studies may be designed to elicit judgments of how undesirable it is to remain a severe asthmatic for a certain period of time as compared to a moderate or mild asthmatic over that same duration.

Asthma Symptoms

A second area of interest concerns the various symptoms associated with asthma. Because asthma varies greatly from person to person, it is difficult to pinpoint only a few defining symptoms. Studies which were discussed earlier, however, have shown that several symptoms correlated well with asthma severity. In controlled human exposure studies these included cough, wheeze, chest tightness, and shortness of breath (dyspnea). It is expected that each of these symptoms is of greater or less concern than the others. It would be helpful, therefore, to use utility under uncertainty methods to elicit the severity relationships that exist between them.

Frequency of Attacks

The use of utility assessment under uncertainty would also appear to be a good vehicle to elicit subjective valuing of additional asthma attacks. It is possible, for example, to find what range of asthma attack frequency is relatively acceptable to an asthmatic or at what point one additional attack would become intolerable.

Pilot Study Protocols

Three pilot studies have been designed to test the effects of each of the various utility assessment variables discussed above and listed in Table 1.

Table 1
Utility Assessment Variables

Subject Group:	Asthmatics Non-asthmatics
Elicitation Method:	Time Trade-Off (TTO) Standard Gamble (SG)
Elicitation Format:	Interview Questionnaire

Each of the pilot studies also addresses one of the three areas concerning asthma with different combinations from Table 1.

Pilot Study 1

The first study attempts to elicit the preference relationship of three severity levels of asthma (severe, moderate, mild) over differing periods of time. The order is expected to remain the same; however, it is anticipated that the relative differences on a quantifiable scale may change over time.

Elicitation Method

Of the two elicitation methods that have been discussed, the TTO method is better suited for the type of test in which time is involved. In fact, it was specifically designed for this type of application. The time trade-off technique is used to elicit preferences for various lengths of time in a specific health state. It involves presenting the subject with a choice of two options, and in the case of severe asthma, for example, the options would appear as follows:

A		B
A guarantee of x years of good health	or	A guarantee of y years of severe asthma

The number of years in option A is varied until the subject is indifferent between A and B. In each of the two options the health state is guaranteed for only the time indicated. After that period, what might happen is unknown; it may be asthma, good health, or immediate death. It is expected that the subject will prefer fewer years of guaranteed good health to a greater number of years with asthma. The process is repeated for various time periods (y_i), and in each case a corresponding good health duration (x_i) is elicited from the individual. The resulting values may be plotted on an x - y axis.

The same process may also be performed for the various severity levels of asthma, therefore creating a comparison of the three. It is hoped that a comparison of the curves would indicate whether the preference relationship of the three severity levels would remain in equal ratios over time or if the more severe levels become disvalued at the greater durations.

For the sake of clarity the subject is provided with a written description of the various health states being considered in the study. Good health is defined as the lack of any major illnesses and each of the severity levels by changes in lifestyle caused by the asthma. These lifestyle effects are listed in Table 2.

Table 2
Criteria Used to Define Asthma Severity

Symptom Frequency:	wheeze cough chest tightness dyspnea
Frequency of Attacks	
Number of hospital/doctor visits per year	
Necessary Treatment (frequency, type, possible side effects)	
Lifestyle Changes:	work or school missed physical activity tolerated avoidance of precipitating factors

For each of the three levels of asthma a different description is provided to the subject using the terms in Table 2 to define it.

Subject Group

Because this is only a pilot study and only very general trends are of interest, it is possible to select a small sample size of subjects. Consequently, it is expected that the number of participants will be kept between three and ten. This first pilot study is designed to compare responses for asthmatics and non-asthmatics; therefore, a group of each must be selected. The asthmatic group will consist of several asthmatics who will be contacted through their physician and will be interviewed during a regular hospital clinic visit. The non-asthmatics consist of a similar sized group of EPA staff members and other individuals who are familiar with the methods of utility under uncertainty.

Elicitation Format

This test also compares the two types of elicitation formats: interview and questionnaire. The interview consists of a series of questions in which the subject is presented with options (A or B) as described above. For example, the subject is asked whether y years of asthma or x years of good health are preferred. The interviewer reduces the number of years of good health until indifference between the two exists. To control bias, however, it is necessary that this not be done in a stepwise manner. The interviewer, therefore, must alter the years of asthma (y) for each question. To assist in this, a tally sheet is provided to the interviewer which consists of a grid with the years of asthma (y) on the y-axis and the years of good health (x) on the x-axis. Each box in the grid represents a comparison of an x with a y. The interviewer may easily select any box and ask the preference of the subject. Once the preference is recorded, the interviewer chooses another box in a predetermined random order. A different tally sheet is necessary for each of the three asthma severity levels and, switching between the three levels is also necessary during the random sequence.

The questionnaire does not involve the tally sheet; however, it does involve the presentation of a random sequence of options for which the subject must indicate a preference or indifference.

Pilot Study 2

The second of the three pilot tests investigates the preference relationships of four symptoms: wheeze, cough, chest tightness, and dyspnea. Once again, both asthmatics and non-asthmatics are interviewed. The questionnaire format, however, is not used in this test. In addition, this test only uses the standard gamble technique. To explain its use in this application one symptom, dyspnea, is discussed as an example.

The severity of dyspnea is best described by discrete levels as shown in Table 3.

Table 3
Severity of Dyspnea

None	no shortness of breath at any time
Mild	shortness of breath with strenuous exertion
Moderate	shortness of breath with moderate exertion (e.g., climbing one to two flights of stairs or walking four or five blocks)
Severe	shortness of breath with minimal exertion (e.g., climbing one-half to one flight of stairs or walking half a block or performing housework)
Dyspnea at rest	shortness of breath without any physical activity

Source: reference (117)

Because of the lack of continuity it is possible to use only the probability equivalence method. This involves presenting the subject with a pair of options to elicit a preference of indifference. For example, the subject may be asked to choose between two options, A and B:

A		B
A guarantee of moderate dyspnea for the remainder of one's life	or	A chance of no dyspnea with a probability of p and dyspnea at rest with probability 1-p

The value of p is altered by the interviewer until indifference between the two options exists. This may be done in much the same manner as in pilot test 1 (i.e., using a tally sheet). This process should produce utility levels for each of the various severities of dyspnea.

The other three symptoms are also tested in a similar manner. In some cases, however, it is possible to use the certainty equivalence method as well. The severity of wheeze and chest tightness, for example, can be considered continuous variables if frequency of occurrence is used to determine the severity of the symptom.

Pilot Study 3

The final pilot study attempts to elicit utility curves of the frequency of asthma attacks. Because it may be difficult to accurately describe to a non-asthmatic what an asthma attack is like, this test is restricted to asthmatics. Furthermore, the information of interest lends itself better to standard gamble methods, and because the variable being tested is continuous (# of attacks) both the certainty equivalence and probability equivalence methods may be used.

As in pilot test 2 , the subjects are presented with two options, A and B. For example,

A		B
z attacks per year with certainty	or	An equal chance of the maximum possible imaginable attacks in one year or no attacks during the year

The value of z is altered by the interviewer in much the same manner as in pilot test 1 and 2 using a tally sheet as an aid. A utility curve is drawn from the resulting data.

CONCLUSIONS

The assessment of the likelihood of effects of air pollution on sensitive populations, such as asthmatics, plays an important role in the regulatory process and standard setting by the EPA. The subjective judgments of the nature and value of these effects by the individuals affected may also add valuable input to these processes. It is useful, therefore, to attempt to elicit utility under uncertainty judgments from such populations. To do this several possible pilot tests have been suggested. It is anticipated that the results of these pilot tests will provide information to the EPA concerning how asthmatics value effects. Furthermore, performing such valuations will also increase the awareness of EPA about the use of utility under uncertainty, its advantages, disadvantages, and areas for further study.

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