COMMON MISTAKES IN MAKING VALUE TRADE-OFFS

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Value trade-offs define how much must be gained in the achievement of one objective to compensate for a lesser achievement on a different objective. Value trade-offs that adequately express a decision maker's values are essential both for good decision making in multiple-objective contexts and for insightful analyses of multiple-objective decisions. This paper identifies and illustrates 12 important mistakes frequently made that limit one's ability to determine useful value trade-offs. It then suggests how to avoid making these mistakes. The intent is to provide practical advice for making good value trade-offs, and hence, better decisions.

1. INTRODUCTION

Most important decisions involve multiple objectives, and usually with multiple-objective decisions, you can't have it all. You will have to accept less achievement in terms of some objectives in order to achieve more on other objectives. But how much less would you accept to achieve how much more? The answers specify a value trade-off and indicate two consequences that are indifferent to each other. Making the judgments about how much you would give up on one objective to achieve specific amounts on other objectives is the essence of value trade-offs. Consider the following example.

A designer and seller of wireless telephones outsources manufacturing. It requests proposals from prospective manufacturers and evaluates offers in terms of cost and quality of the telephones. The cost is measured in terms of dollars per telephone and quality by the failure rate of telephones that malfunction in the first 90 days of use. For one of next year's models, the company has received two offers: One company will charge \$200 and the expected failure rate is 8%; the other company will charge \$230 with an expected failure rate of 4%. Which of these two alternatives is preferred?

Knowing this information, the issue is whether a decrease in cost from \$230 to \$200 is preferred to, indifferent to, or less preferred than a decrease in failure rate from 8% to 4%. This judgment requires a value trade-off between cost and failure rate, which states specific changes in both cost and failure rate that result in one being equivalently well off. Suppose one makes the judgment that the reduction in value due to an increase in cost from \$200 to \$225 is exactly compensated for by a decrease in the failure rate from 8% to 4%. This implies that phones that cost \$200 with an 8% failure rate are indifferent to phones that cost \$225 with a 4% failure rate. Obviously, phones that cost \$225 with a 4% failure rate are preferable to phones that cost \$230 with a 4% failure rate, since both have 4% failure rates and the \$225 price is preferred to \$230. Using the logic of transitivity, it follows that the offer of phones for \$200 with an 8% failure rate is preferred to the offer of \$230 with a 4% failure rate. In this example, the specific value trade-off made was that the decrease in value due to an increase in costs from \$200 to \$225 is exactly compensated for by a decrease in the failure rate from 8% to 4%.

This example may make it seem simple, yet making value trade-offs is one of the most difficult elements faced in important decisions. Value trade-offs are necessary to make smart choices in any decision involving multiple objectives. These value trade-offs must be made either implicitly or explicitly. When made explicitly, most of the time, value trade-offs are used to facilitate clear thinking about the choice. Sometimes an analysis of the alternatives is conducted that incorporates the value trade-offs in the evaluation. Decision analyses, cost-benefit analyses, multiple-objective programming, or any analysis of a multiple-objective decision must include value trade-offs.

To determine useful value trade-offs for a decision, there are two requirements. First, focus your efforts on the substance of the value trade-off issues of that decision. Second, avoid errors and biases in the assessments of the value judgments necessary to quantify the value trade-offs. In short, first do the right thing and second, do it right. In attempting to address the substance of the value trade-off issues, several commonly made mistakes can lead you astray. The purpose of this paper is to describe these mistakes and indicate how to avoid them. We also call attention to many assessment errors and biases that can hamper assessments, and our suggested procedures attempt to minimize their impact. However, a separate paper could address this second requirement to obtain useful value trade-offs.

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2. UNDERSTANDING VALUE TRADE-OFFS

A key reason for many mistakes in making value trade-offs is that the concept of a value trade-off is frequently misunderstood. Take a very simple example. Suppose you are reasonably hungry and have \$30 in your pocket. Your hunger is such that you would be indifferent between eating a hamburger and keeping \$20 and not eating the hamburger and having \$30. In other words, your value trade-off for the hamburger is \$10. This means that you would be willing to pay up to \$10 for that hamburger *if you had to*. However, suppose there is a convenient location where you could purchase a hamburger for \$4. Now, you are willing to pay only \$4 for the hamburger (and not more) and keep \$26 in your pocket. Such a decision makes you better off: Having eaten a hamburger and keeping \$26 is preferred to having \$30 and not eaten a hamburger. Your value trade-off for the hamburger is \$10, whereas the trade-off that you are willing to make *given the choices available* is to pay \$4 for a hamburger. For this reason, in lay terminology, we refer to a value trade-off as an "even swap" (Hammond et al. 1999), as you are equally well off after an exchange based on a value trade-off is made.

Value judgments are required to make value trade-offs. You cannot determine them exogenously from information other than your value judgments. For instance, from knowing only that hamburgers are available for \$4, you cannot determine the value trade-off for a hamburger.

Value trade-offs work reciprocally. Recall in the wireless telephone example that a value trade-off was that the decrease in value due to an increase in cost from \$200 to \$225 was compensated for by a decrease in the failure rate from 8% to 4%. Thus, the consequences (\$200, 8% failure rate) and (\$225, 4% failure rate) are indifferent. Hence, a reciprocal value trade-off is to accept an increase in the failure rate from 4% to 8% in exchange for a decrease in cost from \$225 to \$200 per telephone.

Making good decisions requires good value trade-offs. This raises the issue of what is a good value trade-off. A good value trade-off is one that accurately represents your views. Making decisions consistent with good value trade-offs will lead you to choose alternatives that, using your values, are more desirable than other alternatives you could have chosen. Like any value judgments you make, you must be the final judge about whether they are appropriate for you. Sections 4 and 5 discuss several mistakes to avoid and guidelines to follow to enhance the likelihood that you make good value trade-offs. Section 3 outlines a framework to think about these value trade-offs.

3. THE BASIC MODEL TO ASSESS VALUE TRADE-OFFS

Value trade-offs can be defined specifically using a basic value model. Let us characterize the objectives of a decision by $O_1, \ldots, O_n$, where n is at least 2, as you need at least two objectives to have value trade-offs. Define $X_1, \ldots, X_n$ to be a set of measures (i.e., attributes) that describe the degree to which the respective objectives are met. Then a consequence can be described as $x = (x_1, \ldots, x_n)$, where x_i is a specific level of X_i.

A value trade-off specifies, and can be elicited by determining, two consequences that differ in terms of two measures and that are indifferent to each other. When there are more than two objectives (i.e., $n > 2$) and we talk about value trade-offs between objectives O_1 and O_2, we are assuming that the levels of the other objectives are held fixed. When $n = 2$ and we talk about value trade-offs between objectives O_1 and O_2, we are still assuming that all other factors, including objectives that are not stated, are held fixed.

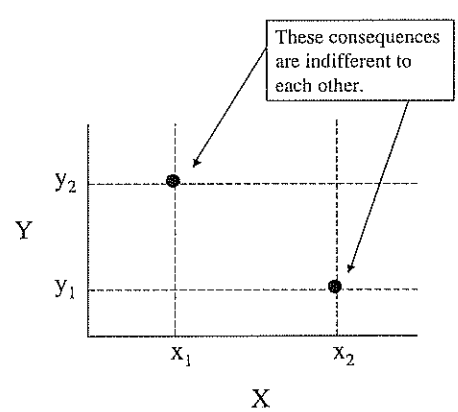
We need only two objectives for illustrations in this paper, so we can denote the measures for objectives O_1 and O_2 as X and Y respectively. We represent a consequence by (x, y) where x and y are specific levels of X and Y, respectively. For our wireless telephone example, our two objectives were to minimize the cost of telephones and to maximize their quality. The measures X and Y used were, respectively, the cost of the telephone in dollars and the failure rate in percent. Then, (\$210, 5%) means a consequence where the cost of the telephone is $x = \$210$ and the failure rate is $y = 5\%$.

To specify a value trade-off, we can determine two consequences that are indifferent to each other. For instance, suppose that given a number of questions, it is determined that (x_1, y_2) is indifferent to (x_2, y_1) in Figure 1. This indifference pair specifies a value trade-off that has four equivalent interpretations:

- From (x_1, y_2), an increase in X to x_2 is compensated for in terms of value by a decrease in Y to y_1.
- From (x_2, y_1), an increase in Y to y_2 is compensated for in terms of value by a decrease in X to x_1.
- From (x_1, y_1), an increase in X to x_2 and an increase in Y to y_2 are equally valued.
- From (x_2, y_2), a decrease in X to x_1 and a decrease in Y to y_1 are equally valued.

The two consequences (x_1, y_2) and (x_2, y_1) would also be on the same indifference curve, which is a curve describing

Figure 1. Aid to interpreting value trade-offs.



a complete set of consequences that are each indifferent to each other.

To specify a value trade-off does not require an indifference curve or an objective function. Rather, these are constructed based on value trade-offs. On the other hand, given an indifference curve, one can determine a set of value trade-offs represented by that curve. Given an objective function, one can obtain a mathematical representation of an indifference curve simply by setting the function equal to a constant. Indeed, a common way to determine a set of all indifference curves is to first determine an objective function.

When doing analysis of a multiple-objective decision, one often constructs an objective function based on value trade-offs and other preference information such as one's attitude towards risk. One popular objective function is the additive utility function (see Fishburn 1965). With two objectives, the additive utility function is

$$u(x, y) = k_1 u_1(x) + k_2 u_2(y), \tag{1}$$

where u is the utility function over the two objectives, u_1 and u_2 are single-objective utility functions over the corresponding objectives, and k_1 and k_2 are scaling factors that are specified by a value trade-off. To determine these scaling factors, one equates the utility of the two indifferent consequences using (1) to create one equation with k_1 and k_2 as unknowns. Normalizing so $k_1 + k_2 = 1$ provides a second equation from which the k_is can be solved. The scaling factors weigh contributions of the different objectives to the desirability of alternatives. Hence, the value trade-offs are critical to making smart choices in complex decisions.

Before proceeding, it is useful to comment on two slightly more technical matters about the relevance of the ideas in this paper. The first concerns value functions and utility functions and the second concerns objective functions that are not additive.

Analogous to the additive utility function, Dyer and Sarin (1979, 1982) discuss conditions necessary for the existence of an additive measurable value function with the same general form as (1). The difference is that u in this case is a measurable value function useful for evaluating alternatives (i.e., consequences) that do not involve risk (i.e., uncertainties) and the u_i are single-objective measurable value functions. The k_i are scaling factors with the same interpretation as in (1). All of the mistakes discussed below and the assessment procedure for value trade-offs suggested in §5 are relevant to both value functions and utility functions. In both cases, the assessments of value trade-offs to obtain the scaling factors involve preferences for consequences that do not involve risk.

There are many objective functions that are not additive and a large body of technical literature that discusses conditions under which different functional forms hold (Keeney and Raiffa 1993, von Winterfeldt and Edwards 1986, Kirkwood 1997). A nonadditive two-objective example is the utility function

$$u(x, y) = k_1 u_1(x) + k_2 u_2(y) + k_3 u_1(x) u_2(y), \tag{2}$$

where all terms are defined as in (1) except k_3 is a third scaling factor and now $k_1 + k_2 + k_3 = 1$. In addition to this normalization, we need to generate two additional equations by equating utilities of indifferent consequences using (2). Then the three equations can be solved to obtain the k_i. In determining each pair of indifferent consequences, value trade-offs are necessary. For each of these, the mistakes and the recommended assessment procedure discussed below are relevant.

4. MISTAKES MADE IN DETERMINING VALUE TRADE-OFFS

It has often been said that the biggest error made in addressing a problem is to address the wrong problem. To determine good value trade-offs, you need to address the substance of the value trade-off problem. This paper is concerned with addressing that substance, so you deal with the *right* problem. There are many potential mistakes that can lead one awry in this task.

The mistakes, listed in Table 1 and discussed below, are commonly made in determining value trade-offs. Some concern understanding the task. Others concern structuring the decision problem to be addressed. Still others occur in determining the judgments necessary to specify the value trade-offs, which is referred to as assessing the value trade-offs. These mistakes frequently cascade. For example, not understanding the task well often leads to a poor structuring of the decision problem, which results in inadequate value judgments.

One way or another, the result is that the expressed value trade-offs do not represent the true interests of the decision maker. When this occurs, the value trade-offs provide little or no insight, contribute to a poor decision, and result in frustration with the decision process.

Mistake 1: Not Understanding the Decision Context. It is necessary to understand the decision context to make good value trade-offs. This means that you should know what the decision is, what it is intended to accomplish, and what types of alternatives are available. It is also important

Table 1. Twelve common mistakes in making value trade-offs.

Mistake 1. Not Understanding the Decision Context.
Mistake 2. Not Having Measures for Consequences.
Mistake 3. Using Inadequate Measures.
Mistake 4. Not Knowing What the Measures Represent.
Mistake 5. Making Trade-Offs Involving Means Objectives.
Mistake 6. Using Willingness to Swap as a Value Trade-Off.
Mistake 7. Trying to Calculate Correct Value Trade-Offs.
Mistake 8. Assessing Value Trade-Offs Independent of the Range of Consequences.
Mistake 9. Not Having Value Trade-Offs Depend on Where You Start.
Mistake 10. Providing Conservative Value Trade-Offs.
Mistake 11. Using Screening Criteria to Imply Value Judgments.
Mistake 12. Failure to Use Consistency Checks in Assessing Value Trade-Offs.

to understand the time scale for the decision and whose perspective the stated value trade-offs are meant to represent.

Suppose you are considering four different jobs at a particular company. The jobs differ in terms of your monthly pay and hours worked per week, where your objectives are to maximize pay and to minimize hours worked (to perform your job well). In deciding whether you prefer the consequence of $4,000 per month working 50 hours per week or $7,000 per month working 80 hours per week, it may be relevant to know whether the time period you are considering in this situation is six months or five years. It might be worth the extra money from working 80 hours per week for a six-month period, but this may not be the case for a five-year period.

In an important decision facing a utility company, two of the objectives were to minimize electricity costs to ratepayers and to maximize the return to company shareholders (Keeney et al. 1986). Executives at the utility company were asked to consider whether they would prefer an average electricity bill for a residential customer of $50 and a 6% return to shareholders, or an average monthly bill of $65 and an 8% return to shareholders. In this decision context, it is necessary to know whether the perspective taken should be that of the shareholder, the ratepayer, a combination of these, or the public utility commission of the state. One could imagine that each of these parties may have different value judgments on what appropriate value trade-offs would be in this situation. Also, these value judgments may depend on the inflation rate.

Mistake 2: Not Having Measures for Consequences. You cannot make reasonable value trade-offs without an understanding of the consequences being considered, yet almost everyone will answer questions that seemingly address value trade-offs without such an understanding.

During a training program for television and newspaper reporters on environmental risk, I asked the following: In the clean up of hazardous waste sites, rank the following in order of importance: economic costs of the clean up, potential human life loss or sickness due to the hazard, potential damage to the environment (i.e., flora and fauna). Perhaps not surprising was that 79 out of 80 participants ranked potential human life loss or sickness first, then environmental damage, then economic costs. However, no one asked how much human life loss or environmental damage or costs are being considered. When I then asked participants to rank the importance of spending $3 billion, avoiding a mild two-day illness to thirty people, or destroying ten square miles of mature, dense forest, their preferences completely flipped. Obviously, spending $3 billion is more significant than avoiding mild illness to thirty individuals for two days. We could spend $3 billion and get much more for our money in terms of better health or in terms of better environment or both. So what did their original rankings mean? The answer is nothing. The mistake is that you cannot think clearly about value trade-offs without some consideration of the consequences, and an appropriate way to do this is to have measures for them.

A specific case from Breyer (1993) is insightful. A toxic waste dump in southern New Hampshire was mostly cleaned up, but a small amount of diluted toxic material remained. It could be removed by incinerating the dirt, which could, in theory, alleviate any possible health effects in the future. Perhaps thinking that health effects were more important than cost, without considering how much of each was at stake, one party litigated to have $9.3 million spent for the clean up. During the court case, it was learned that all parties seemed to agree that the waste dump was already clean enough for children playing on the site to eat small amounts of dirt daily for 70 days each year without significant harm. Burning the soil would make it clean enough for children to eat dirt for 245 days out of the year without significant harm. However, there were no children in the area, as it was a swamp. Understanding the consequences in terms of additional cost and changes in potential health impacts should make a choice like this straightforward.

Mistake 3: Using Inadequate Measures. Similar to the mistake above, if you have an inadequate measure, you can't understand what the consequences are. Hence, you can't make reasonable value trade-offs. Consider expensive medical programs intended to save lives. Suppose the objectives are to maximize lives saved and minimize costs. The number of lives saved may be selected as the measure for the first objective. Note that this measure counts the saving of a ten-year old the same as saving an eighty-year old. Hence, if two competing programs each cost $10 million and one saves 20 ten-year olds and the other saves 25 eighty-year olds, the second program would be preferred using the number of lives saved measure.

Many people may feel that saving 20 ten-year olds is more important. They may argue that each ten-year old that dies loses 70 years of expected life, and each eighty-year old loses ten years of expected life. So the first program would save many more years of expected life. For these people, the mistake is that the measure is inadequate, as it has implicit value judgments that may not make sense. People may not feel that saving a ten-year old or an eighty-year old is equally desirable, as the measure implies. To rectify this, one might either choose the measure of collective years of expected life lost or weight the relative importance of death at different ages.

A general situation in which one might not recognize an inadequate measure is where both the quality and the quantity of some consequence matters. For instance, in many development decisions impacting streams in the Pacific Northwest, one of the objectives is to minimize the environmental impact on salmon in those streams. In one study, an initial measure chosen for this objective was the reduction in the number of salmon in subsequent annual runs (Keeney and Robilliard 1977). However, trading off reductions in the salmon run against other environmental consequences or costs of building a power plant proved to be very difficult. The reason was that a reduction of 1,000 fish in a stream that averages 2,000 per annual salmon run

was much more important than a reduction of 1,000 fish in the Columbia River that has an annual salmon run of 1,000,000 fish. The former was more important because 50% of the run might be depleted, whereas only 0.1% of the run in the Columbia would be lost.

Similar situations arise in projects that could result in the loss of forests. An obvious way to measure this is by acres of forest lost. However, an acre in one forest is not necessarily equivalent to an acre in another forest. One may be much more dense than the other, or have better-quality trees, or be part of a wilderness area, or provide higher-quality habitat for mammals. Obviously, such considerations could greatly affect the value of an acre of forest. In complex situations like this, it may be necessary to build a model involving physical and social attributes and relate them to measures of the fundamental objectives of value.

Mistake 4: Not Knowing What the Measures Represent. The forest example helps illustrate a related mistake. When valuing an acre of forest, is it the trees that are being valued, or the trees and the habitat they provide for other flora and fauna? The appropriate answer depends, of course, on the consequences that might occur and on the other objectives explicitly listed in the decision.

Suppose two objectives are to minimize the loss of forest (for the direct value of the trees) and to minimize the loss of large mammal habitat. Then, losses in one forest that is a large mammal habitat count as consequences regarding both of these objectives, whereas losses in a forest that is not a habitat counts as only the first. If we appropriately made value trade-offs between loss of forest for its tree value and loss of forest for its habitat, then both would be appropriately counted in the decision. The forest without habitat would naturally be valued less per acre than the forest with habitat.

Issues such as this routinely occur on Internet websites concerned with evaluation. *Money Magazine* provides an annual evaluation of the best metropolitan areas in which to live. In 1999, they put their evaluation scheme on the Internet so individuals could evaluate metropolitan areas based on their own preferences (*Money Magazine* 2000). To evaluate the economy of regions, one measure used was the cost-of-living index, which was normalized to average 100 across the country. The Money website stated that the cost-of-living index ranged from a low of 86.2 in Fort Smith, Arkansas, to a high of 237.7 in New York. It then asked an individual to set an ideal value.

Quite frankly, this request is stupid and leads to worthless value trade-offs. If the cost of living index is to evaluate only economic costs, then the lower the better, so 86.2 is the ideal given my preferences. On the other hand, if this index is also to represent the potential benefits that arise from having a higher cost of living, my ideal value may be much higher. Depending on the interpretation, I would be willing to give up some benefits in terms of other objectives either to lower the cost-of-living index or to raise it. It is clearly very important to understand what the measure is meant to represent to make reasonable value trade-offs.

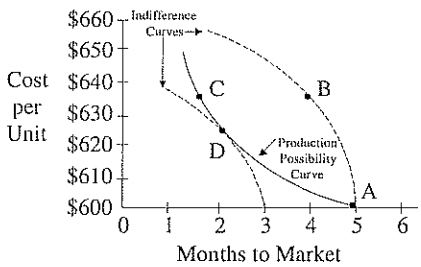
Mistake 5: Making Trade-Offs Involving Means Objectives. In evaluating alternatives, it is important to use a set of fundamental objectives for the decision being addressed (Keeney 1992). It is easier to make good value trade-offs among fundamental objectives, because the fundamental objectives state the reason for being interested in the problem. In problems involving air pollution, two objectives are to minimize the cost of reducing air pollution and minimize the number of health effects (sometimes deaths) attributable to air pollution. However, in many analyses of air pollution problems, a means objective—namely, to minimize the air pollutant concentration—is used as a proxy for the fundamental objective—to minimize health effects. This practice leads to the following conundrum. How can one thoughtfully make value trade-offs between an air pollutant concentration and cost?

A specific example concerns a national air quality standard for carbon monoxide (CO). Suppose it costs $3 billion annually if CO concentrations are limited to 3 parts per million, and suppose that the standard costs $6 billion if concentrations are held at 2 parts per million. What are the value trade-offs between costs and the limit on the air pollutant concentrations? Is it worth $3 billion to lower concentrations from 3 parts per million to 2 parts per million? The only way to think clearly about this is to try to understand what health effects might be caused by concentrations of 2 parts per million and 3 parts per million. This is an extremely difficult task that very few people would be able to do well informally. The appropriate way to address this is to model the casual relationship between pollutant concentrations and potential health effects, recognizing of course the uncertainty in this relationship. Then one could deal directly with the value trade-offs between costs of the national air quality standard and the health effects averted (Keeney et al. 1984).

Fischer et al. (1987) did some interesting experiments to show how using the means objective in this context results in inappropriate value judgments. They assessed value trade-offs between costs of an air pollution control program and air pollutant concentrations, and also between costs of that air pollution control program and health effects avoided. The same people answered the value trade-off questions in both situations and were given the probabilistic relationship between concentrations and the health effects. The result was that individuals tended to put a greater weight on the air pollution concentrations than would be warranted based on their value trade-off between the fundamental objectives of cost and health effects averted.

Mistake 6: Using Willingness to Swap as a Value Trade-Off. A value trade-off both defines and is defined by two consequences that are indifferent to each other. The interpretation is that you would be equally satisfied (or dissatisfied) if you had either consequence. As illustrated with the hamburger example in §2, this does not mean that you would be willing to swap one consequence for the other. The reason is that there may be alternatives that increase

Figure 2. Production possibility curves do not express value trade-offs.



your satisfaction and you would rather do this than keep it the same.

Consider the final design stage for a particular computer. The objectives are to minimize the cost of manufacturing the computer and to minimize the time to market. These objectives are measured by the manufacturing cost per unit and months to market as shown in Figure 2. This figure illustrates two indifference curves by dashed lines and the production possibility curve by the solid line. The production possibility curve indicates that Consequence A represents the lowest-cost computer ($600) and that its anticipated time to market is five months. Based on the indifference curve through this consequence, a value trade-off at ($600, five months) is that the loss in value due to increase in unit cost of $35 is compensated by a decrease in the time to market of one month to four months. Hence, Consequence A and Consequence B meaning ($635, four months) are equally preferred. However, the company would not be willing to exchange A for B, as an alternative indicated by Consequence C, namely ($635, one and a half months) on the production possibility curve reduces the time to market to one and a half months for that $35 investment. Even better than Consequence C is Consequence D of ($625, two months), where the production possibility curve is tangent to the indifference curve. Given the production possibility curve and the value trade-offs represented by the indifference curves, the best decision for the company is to produce a $625 product that comes to market in two months.

Mistake 7: Trying to Calculate Correct Value Trade-Offs. There are no externally correct value trade-offs. Your value trade-offs must be based on your value judgments. Hence, they cannot be calculated or determined directly from other information without using your value judgments. However, information and calculations are often useful to help make meaningful value trade-offs.

Numerous government programs spend large amounts of money to save lives of citizens of the United States. These programs concern pollution reduction, automobile safety, equipment and job safety, and medical and health programs (Tengs et al. 1995). To make an appropriate value trade-off between the cost of the program and the potential expected lives saved from that program, it may be useful to calculate the cost of reducing risks that save lives in other programs.

Consider this example. Suppose calculations indicate that each $10 million invested in an existing Program A to reduce a specific air pollutant reduces the expected loss of life by one individual. This suggests that the value trade-off between lives saved and cost in Program B to reduce a different air pollutant should be no greater than $10 million for every life saved. To see this, suppose the value trade-off in Program B was set at $50 million per life saved, meaning that we should spend up to $50 million to save one life. Each $50 million spent to save a life using Program B will not be available for Program A that saves lives for each $10 million invested. The result saves one rather than five lives, and the same people may be subject to both pollutants.

There are other uses of calculations to help determine appropriate value trade-offs. In many decisions that concern the siting and construction of major facilities, such as power plants or transmission lines, a common issue is aesthetics. The fundamental objective is to minimize degraded views. When one considers trading off the cost of the project versus its degraded views (i.e., how much it is worth to make it less unsightly), important information concerns how many people will view the site or the transmission lines. This information might be gathered by survey or calculated.

Calculations frequently help one to better understand the implications of different levels of achieving objectives, and this provides a basis to make better-informed value trade-offs. For example, different upgrades to water treatment facilities may be considered to reduce the amount of pollution dispersed into the surrounding waters. Natural measures for the objectives of minimize cost and minimize pollution emissions are the cost of the project in dollars and tons of emissions. However, to better represent how important a particular cost is, it may be useful to calculate the annual cost that each homeowner would pay to construct the facility. In a sense, this may be thought of as changing the measure of the cost objective, but operationally it is better to keep both measures. Hence, the cost of a facility might be described as $25 million, resulting in an additional $50 per year for water for each homeowner.

Mistake 8: Assessing Value Trade-Offs Independent of the Range of Consequences. Suppose you are considering purchasing a new house because your child is now ready to attend school. You examine several houses and narrow the choice to six alternatives, each in a different school district. The houses are more or less equivalent except in terms of cost and the quality of the school districts. Your objectives are to minimize house costs and to maximize the quality of the school district. The respective measures are cost in thousands of dollars and the percentage of the student body performing above the national average on standardized tests. In terms of these measures, the houses you are considering range in cost from $160,000 to $240,000 and in percentage of students performing above the national average from 57% to 86%.

In an attempt to help you, a well-meaning realtor might state something like the following: "It all comes down to whether the cost of the house or the quality of the school district is more important. Which is more important to you?" This is a misguided question that does not really address your value trade-offs.

If you answered that school quality is more important, does this imply that a $240,000 house with 75% of students performing above the national average is preferred to a $160,000 house with 72% of students performing above the national average? Likely not. If you answered that housing cost is more important, does this mean a $179,000 house in a district where 47% of the students perform above average is preferred to a $185,000 house where 86% of the students perform above average? Again, likely not. Either way, your answer to such a question frequently results in a misrepresentation of your value trade-offs. The problem is the same as that leading to Mistake 2; you must know how much of each consequence you are talking about in order to make reasonable value trade-offs.

To make the point another way, suppose that you are asked "Which objective is more important, the cost of the house or the cost of the house?" If you heard such a question, you would think that it was misstated. But suppose you were asked which is more important, the increase in the cost of the house from $160,000 to $240,000 or from $180,000 to $210,000? Here you could easily answer that the change from $160,000 to $240,000 is much more important. The change from $180,000 to $210,000 makes the house more difficult to afford, whereas the $80,000 jump to $240,000 may make the purchase almost impossible. Thus, in making value trade-offs between cost and school quality, you would need a greater increase in school quality to compensate for an increase in housing costs from $160,000 to $240,000 than from $180,000 to $210,000.

Several experiments have empirically demonstrated the mistake of assessing value trade-offs independent of the range of consequences. Subjects are given questions with at least two alternatives described in terms of consequences on two or more objectives. The ranges of those consequences are varied in different questions. Subjects are typically asked to rank the importance of a set of objectives for a given decision. Then they are to assign an importance of 100 to the highest-ranked objectives and smaller numbers representing the relative importance of the other objectives. In an early study, Gabrielli and von Winterfeldt (1978) found that the ranges of consequences did not affect the importance weights as they should. More detailed studies, such as Borcherding et al. (1991) and von Nitsch and Weber (1993) got similar results.

Fischer (1995) examined job choices that differed in terms of annual salary and annual paid days of vacation. In two experiments, he again demonstrated the insensitivity of importance weights as assessed above to ranges of consequences. When the assessment procedure was changed to assess so-called swing weights by asking subjects to rank the importance of the ranges of the consequences on the set of objectives and then rate them relative to 100 for the highest-ranked range, there was a sensitivity found for the range. However, it was less than the trade-off procedure that explicitly asked for pairs of consequences that the subject found to be indifferent. Fischer hypothesized the reason for this is that a more explicit focus on what is gained or lost in terms of differed objectives will result in a greater sensitivity of the assessed values to the ranges of consequences.

Mistake 9: Not Having Value Trade-Offs Depend on Where You Start. There is a tendency to assess a value trade-off between the units of measurement of the different objectives and then extrapolate it over the entire range. Such an extrapolation is often done linearly, which is reasonable only if each successive unit change in the different measures has the same values as the previous change. This is not a reasonable assumption when there is risk aversion or diminishing marginal utility (Keeney and Raiffa 1993). In addition, reference points based on such things as goals and aspirations can distort such assessments (Kahneman and Tversky 1979, Heath et al. 1999).

Suppose that in the decision involving housing cost and school quality that an individual stated the following value trade-off. A $10,000 increase in house cost is compensated for by a 5% increase in the number of students performing above the national average. This assessment may have been explicitly, or more likely implicitly, made by thinking about consequences in the range that one expects or hopes to find. For instance, it may refer to a change in the housing cost from $160,000 to $170,000 in exchange for an increase in the quality of the school district from 60% to 65% of the students performing above the national average. If so, it does not necessarily follow that an increase in housing cost from $220,000 to $230,000 could be compensated by a change in school quality from 80% to 85% . It is obvious that this proposed value trade-off involves an increase in cost of $10,000 in exchange for an increase in the quality of school district of 5%. However, an increase in cost from $220,000 to $230,000 may be more significant than an increase from $160,000 to $170,000. It also may be the case that the increase in the quality of the school district from 80% to 85% is not as important as the increase in the quality of the school district from 60% to 65%. Such an extrapolation should not be made without carefully considering such implications and their reasonableness.

Mistake 10: Providing Conservative Value Trade-Offs. Consider a state deciding how much to spend to improve the safety of its highways. The state has the two objectives: maximize lives saved and minimize the cost of the upgrades. In this example, we will assume that it is reasonable that preferences are linear for each measure, meaning that each $1 million spent is exactly as important as the previous $1 million and that each life saved is equivalently valued. State regulators may believe that an appropriate value trade-off is that an increase of $5 million is compensated for by lowering driving risks such that one

additional life is saved. Suppose, however, that individuals making these value trade-offs think as follows: "Just to be safe, we should put a factor of safety of two in this value trade-off and say that an increase in cost of $10 million is exactly compensated for by reducing the risk enough to save one additional life." This sounds noble. However decisions made based on such a value trade-off may be ill advised and result in the loss of additional lives. Why?

Suppose existing information indicates that a life can be saved for each $5 million invested in improving the quality of the highways between the bridges. Also, suppose that analyses indicate that a $500 million investment on bridges could save 140 lives over the next 30 years, the lifetime assumed for the bridge upgrades. Given the value trade-off of $5 million per life saved, such an investment would clearly make sense as it could save lives at $3.57 million per life saved. However, suppose that investment of an additional $500 million (i.e., an increase to a $1 billion investment) could only save 60 more lives, as the more critical bridge upgrades were provided by the first $500 million investment. Using the value trade-off of $5 million per life saved, one would not make this additional $500 million investment as the cost per life saved is $8.33 million. With the conservative value trade-off, such an investment would be made and 60 additional lives would be saved. This perhaps sounds reasonable until one considers the real consequences of the decision.

If the second $500 million investment were made on road improvements rather than on additional bridge upgrades, it would have resulted in a saving of 100 lives, which is obviously 40 more than the 60 saved by the additional bridge upgrades. In such a case, decisions based on the conservative value trade-off result in an unnecessary loss of 40 lives in a 30-year period. It is important to recognize that the individuals at risk in both situations, because of accidents on the bridges and accidents on the roads that connect bridges, are the same. The moral is that conservative value judgments do not make sense and do not necessarily lead to what one might think of as conservative decisions.

Mistake 11: Using Screening Criteria to Imply Value Judgments. Often one is asked questions in purchasing contexts such as the following: "What is the maximum you would be willing to pay for a car?" Suppose you say $25,000. An implication that many take from this is that any improvement on another objective is not worth it if it simultaneously increases the price of the car beyond $25,000. Suppose you live in a hot, humid area and desire air conditioning in your car along with many other features. Suppose further that one particular car with all of these features except air conditioning costs $24,700. The sales person says that air conditioning can be included for $25,300. Even though you said the maximum amount you are willing to pay for the car is $25,000, you may easily conclude that the car for $25,300 with air conditioning is preferable to the car for $24,700 with no air conditioning. This would imply that your value trade-off for that air conditioning is at least $600.

Unfortunately, many websites intended to help you evaluate products (e.g., Activebuyersguide.com 2001) do not currently have the logic comparable to a good sales person. On a now defunct website (Personalogic.com 2000), the $25,300 car would not have been suggested because of the $25,000 screening criteria. An implication is that beginning at $24,700, an increase of more than $300 cannot be compensated for by the addition of air conditioning. Beginning at $24,980, an increase of only $25 is not worth it to include air conditioning. The value trade-offs implied by screening criteria are often inconsistent with your true values.

Used well, screening criteria can help you quickly eliminate inferior alternatives. To do this, screening criteria should be broadly set to avoid eliminating any alternatives that are real contenders. In the car example, this means that you should have set the maximum you would pay for an automobile at $30,000. This implies that you would consider a car with all your desired features except air conditioning that cost $29,950 and not consider a car that added the air conditioning and cost $30,020. However, neither one of these would be your preferred car because they both cost much more than you wish to spend. If you have a good set of value trade-offs, these will provide an appropriate evaluation of all the alternatives that are considered. Reasonable value trade-offs will imply that an increase in cost, from say $28,000 to $30,000, would likely be so significant that it would outweigh most improvements in achieving other objectives. However, they would not imply that a change from $24,700 to $25,300 would be so heavily considered, and hence, what might turn out to be a preferred alternative would not be eliminated from the set under consideration.

Mistake 12: Failure to Use Consistency Checks in Assessing Value Trade-Offs. Value trade-offs are information. They are based on your value judgments and any other knowledge that you have. Eliciting value judgments is subject to bias and random errors (see, for example, von Winterfeldt 1999 and Fischer et al. 2000). Hence, it is important to check the reasonableness of the value trade-offs.

There are two types of checks of value trade-offs. The first involves redundant assessments in determining the value judgments. Consider different plans that might clean local estuaries or lakes by reducing runoff from fertilizer and erosion damage from roads and commercial activity in the area (e.g., Gregory 2000). Three objectives might be to minimize the cost of the program, maximize the quality of the water resource, and minimize the loss of jobs. These might be measured respectively by dollars, annual adult fish in the local water, and jobs lost. It might be decided that a reasonable value trade-off is that an additional cost of $500,000 is exactly worth a 2,000 increase in annual fish in the region, given that jobs are held fixed. Another value trade-off may be that a $500,000 increase in program costs would be compensated for by preserving 10 local full-time jobs. As a consistency check, one might trade off potential job loss with the local fish. To be consistent, it should

be the case that a loss of 10 local full-time jobs would be compensated for by an annual increase in local fish of 2,000. However, in making this value trade-off, individuals may state that a decrease of five full-time jobs is indifferent to an increase of 2,000 fish annually. Such a response is inconsistent with the previous two stated value trade-offs. Inconsistencies are not unexpected, as making value judgments is difficult. Based on such an inconsistency, one should review the full set of value judgments and adjust them such that they become consistent. It is partly through this process of modification and improvement that we can construct better value trade-offs.

Given a consistent set of value trade-offs, as mentioned in §3, we can construct an objective function that captures all possible value trade-offs. A second type of consistency check involves testing the implications of this objective function. In the example above, it may be that an increase in local fish of 2,000 per year refers to an increase from the current 3,000 to 5,000. If one had an objective function, it may indicate that an increase from 5,000 to 7,000 fish annually is not as important as the previous 2,000 jump. Indeed, it may be implied by the objective function that an increase from 5,000 to 10,000 fish is needed to compensate for a $500,000 increase in the cost of the plan. This value judgment should be reviewed by those providing the values to see if it represents their interests. The opportunity for many such checks after the objective function is expressed helps in the process of modification and improvement to provide a useful complete representation of the values of the decision maker.

5. MAKING GOOD VALUE TRADE-OFFS

Clear thinking about value trade-offs requires a knowledge of what has been said about value trade-offs in this paper. It is important to understand each of the potential mistakes and how they may hamper determining good value trade-offs. One needs to understand that the value trade-offs between the achievement of two objectives indicate how much of one a person would give up in exchange for a specified amount of another that would result in one being equally well off. In other words, value trade-offs can be characterized by consequences that one finds to be indifferent. It is essential to realize that value trade-offs must be based on value judgments, and that there are no universally correct value trade-offs that can be calculated without value judgments.

Once the general issues of value trade-offs are understood, to determine a useful set of value trade-offs it is essential to focus the assessment on the substance of the specific value trade-off problem. This requires that one not make any of the 12 previously described mistakes. Each mistake is a logical error that results in missing some of the substance of the problem. The four steps below address the substance of value trade-offs and avoid any logical mistakes. This is necessary but not sufficient to result in useful value trade-offs.

Behavioral decision scientists have demonstrated numerous psychological traps in any assessment procedure that hinder the results. See, for example, Kahneman et al. (1982), von Winterfeldt and Edwards (1986), and Baron (1997). Other relevant literature particularly related to making mistakes is referenced in §4. Hence, there are two requirements for assessing good value trade-offs. The first is to do the right thing (i.e., focus on the logical substance of the value trade-off problem), and the second is to do it right (i.e., avoid the psychological traps that influence assessment procedures).

This paper is mainly concerned with the first requirement. The four steps below were developed from experience with applications requiring value trade-offs. The steps also try to minimize the impacts of psychological traps while productively using the available time of the person being assessed. However, I expect that experiments that follow the entire assessment procedure could lend useful insights to further improve the process of how the assessments are done.

Step 1: Frame the Decision Appropriately. The essence of this step is to structure the decision being addressed. This requires one to define a complete set of objectives of interest and a full range of alternatives to evaluate for achieving those objectives. It is important to recognize what the decision process is and who is involved and how. If there is a single decision maker, he or she should be identified. It is important to understand the time frame of the decision.

All participants in assessing the value trade-offs should agree on what perspective each is to take. In a business decision, is the perspective to be taken meant to represent the shareholders, the customers, the employees, or a subset or combination of the three? Should separate value trade-offs be assessed to represent different perspectives? In a public decision, should value assessments try to collectively represent stakeholders' views, or should separate assessments with stakeholders be conducted and then combined in some fashion to represent all stakeholders? Whatever is best for a given decision depends on the decision and the time and resources available. In any case, before assessing value trade-offs, all people involved should be clear about the answers to these questions.

Step 2: Structure the Value Trade-Off Problem. Only value trade-offs between fundamental objectives are appropriate to evaluate alternatives. These fundamental objectives need to be clearly listed. It is often useful to identify any means objectives that contribute to better achieving the fundamental objectives and clarify their relationships to the fundamental objectives.

For each of the fundamental objectives, a clear measure needs to be identified that indicates the degree to which it is achieved. Each measure needs to be clearly understood and meaningful to the decision maker. The value trade-offs necessary to resolve a decision must address the range of consequences that might occur as a result of choosing

an alternative. Hence, it is useful to describe this range of consequences in terms of upper and lower bounds on the measures. If the fundamental objectives, measures, and ranges are specified, they will provide a sound structure for making value trade-offs.

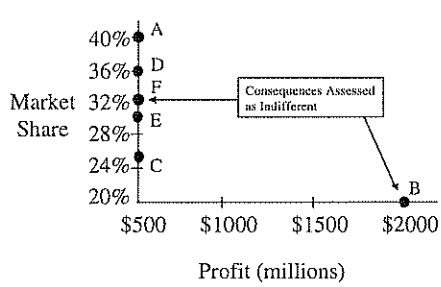
Step 3: Determine Pairs of Consequences That Are Indifferent. It is hard to make value judgments about consequences that differ in their levels of achievement on two objectives. It is much harder to make value judgments about consequences that differ in terms of levels of achievement on three or more objectives. Hence, to make useful value judgments, one should find indifferent pairs of consequences that differ in their achievement of two objectives only.

Indifferent pairs should be found by a bounding and converging procedure. Suppose a major company is considering alternatives to acquire new customers. Its objectives are to maximize profit over the next two years and to maximize the market share of its product at the end of the two-year period. These objectives are measured, respectively, in terms of millions of dollars and percent of market share. Suppose the prospective ranges are $500 million to $2,000 million and 20% to 40% market share. The possible consequence space is shown in Figure 3.

To determine a value trade-off between the two objectives, one might begin by asking which consequence between A, meaning ($500 million, 40%), and B, meaning ($2,000 million, 20%), is preferred. Suppose A is preferred. Then one might reduce the market share of A to another Consequence C that is ($500 million, 25%) and compare it to Consequence B. The market share in C should be chosen such that it seems that B would be preferred. If this is the case, there must be some consequence that has $500 million profit and a market share between 25% and 40% that is indifferent to B. One might sequentially try Consequences D and E and end up with F being indifferent to B.

Since F is ($500 million, 32%), this implies that a reduction in two-year profits from $2,000 million to $500 million is compensated for by an increase in market share from 20% to 32% at the end of two years. Converging to this indifference requires serious thought by the individual whose values are being assessed. To facilitate this thought, begin with easier judgments first. It is easier to state that one consequence is preferred to another than to find two consequences that are indifferent. In the former case, some of the choices of the preferred consequence may be very easy, whereas they get more difficult as you get close to indifference.

Figure 3. A convergence procedure to assess value trade-offs.



Research on assessment techniques (Tversky et al. 1988, Fischer et al. 1999) has indicated many shortcomings (i.e., bias) in how people express their preferences for trade-offs. Collectively, these experiments have certainly demonstrated that the task is complex. That is all the more reason to work hard at it. Not only the results, but the thinking that occurs in the process, are important. Hence, it is desirable to have an assessment that both tries to expose shortcomings of the expressed preferences to the assessee and, simultaneously, reduce their influence.

Fischer et al. (1999) did experiments to examine the prominence effect that indicates that the prominent attribute (most important or salient) receives more weight in choice tasks (choosing which of two consequences is preferred) than it does in trade-off tasks (setting attribute levels so pairs of consequences are indifferent). This difference holds even if the trade-offs are elicited using a convergence procedure as advocated above. In addition, it is not known which procedure leads to the more appropriate preferences. In many situations, the most appropriate value trade-offs may be between those implied by the different tasks. Given this complexity, our assessment procedure is designed to account for and hopefully reduce the prominence effect by including two important facets: (1) Use both choice and trade-off questions as these two procedures tend to have opposite implications regarding the prominence effect (Fischer et al. 1999), and (2) employ consistency checks that force reflection by the assessee and perhaps lead to a better internal understanding expression of value trade-offs.

Step 4: Revise Value Trade-Offs as Appropriate to Assure Reasonableness. Assess more value trade-offs than you need to specify a set of good value trade-offs. This redundancy will no doubt result in some inconsistencies. Recognizing these, keep working with the assessee to revise the assessments to obtain consistency. The process is similar to triangulation in surveying. In surveying, you start at a Location A with a known elevation. You survey to a second Location B and determine its elevation relative to A. From that point, you continue to a third Location C and determine its elevation relative to B. Then you come back to Point A from Point C to determine its elevation. If it is the same as when you started, then the surveying was likely consistent. If you triangulate between a few more locations, this likelihood of any errors decreases significantly, as well as the significance of any remaining errors decreases. The same is true using redundant value trade-offs to specify a good set of value trade-offs.

Often the set of good value trade-offs that you want is the set that is sufficient to specify the scaling factors in an objective function such as (1) or (2). Given this, together with the form of the objective function and any other assessments needed for that function (i.e., single-objective value functions), you have all the information

needed to specify all value trade-offs (Keeney and Raiffa 1993, Kirkwood 1997). From that, you can examine the implications of these value trade-offs to see if they seem reasonable. If some do not represent your true values, then modifications need to be made to either the objective function or to the value trade-offs. The process should continue until you are comfortable with the value trade-offs. At that point, one can confidently evaluate the alternatives.

6. FINAL COMMENTS

Making value trade-offs is a very important part of addressing and resolving complex decision problems. If value trade-offs are made poorly, it is unlikely that a decision consistent with them will be in your best interest. If value trade-offs are made well, you should be able to eliminate all of the poor alternatives and your choice will be among the best.

Value assessments are never as accurate as physical measurements, but they do not need to be. The reason is that a set of good value trade-offs is unlikely to be the information of lowest quality in a decision. These value trade-offs will surely allow us to identify the least desirable alternatives and provide insight for not choosing them. In general, this insight about why different alternatives are preferred and by how much is invaluable.

This paper provides the information that you need to make good value trade-offs. It outlines the conceptual issues and structure for making value trade-offs well. It indicates the common mistakes that individuals typically make in expressing and representing value trade-offs and outlines four simple steps to avoid those mistakes.

Becoming good at making value trade-offs requires practice. Make some value trade-offs on problems that are of interest. If you are not satisfied with the result, note the potential mistakes and revisit the guidelines to avoid them. There is no substitute for meaningful practice in order to learn how to make good value trade-offs.

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