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Attribute Selection for Preference Functions in Engineering Design

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***Abstract*—**Industrial Engineering is a broad multidisciplinary field with intersections and applications in numerous areas. When designing a product, it is important to determine the appropriate attributes of value and the preference function for which the product is optimized. This paper provides some guidelines on appropriate selection of attributes for preference and value functions for engineering design.

***Keywords*—**Decision analysis, engineering design, direct vs. indirect values.

I. Introduction

THE identification of the attributes of value in the design of an engineering product and clarifying preferences about the design is an important task in industrial engineering. The purpose of this paper is to provide some insights into the appropriate choice of the attributes of value and insights on how to construct appropriate preference functions.

II. Direct vs Indirect values

To begin, it is important to make a distinction between "*direct"* and *"indirect"* values [1] for use in expected utility decision making [1]-[6]. Direct value attributes are factors that contribute deterministically to a change in preference. Changing the level of a direct value attribute might change the preference for each prospect of the design or the decision. Indirect values are factors that do not contribute to a change in preference of deterministic prospects. They merely serve as indicators about the likelihood of achieving a level of one or more direct value attributes. To further clarify the distinction between direct and indirect values, consider the African resort hotel owner from [1]. An African resort hotel owner is vitally interested in tourism, because of the revenues associated with tourists, but who is indifferent to the presence of African wildlife. However, the owner knows that the wild animals increase the chance of attracting more tourists, and, therefore, the owner would prefer having more wildlife to less. We say that the owner places a direct value on tourism, and an indirect value on wildlife.

Fig. 1 shows a diagram with two ovals "Tourism" corresponding to profit from tourists, and "Wildlife" corresponding to the abundance of the wildlife habitat. In the diagram, there is an arrow from Tourism to value. This notation implies that tourism is a direct value attribute. The diagram shows no arrow from Wildlife to Value but an arrow from Wildlife to Tourism. Because both Tourism and Wildlife are uncertain a priori, the absence of this arrow implies that Wildlife is an indirect value. The hotel owner is interested in wildlife only because it contributes to more tourism revenues. If this hotel owner was guaranteed a fixed amount of tourism profit regardless of the level of wildlife, he would no longer be concerned about the wildlife.

The tree representation of this situation is on the right side of Fig. 1. The figure shows that the decision maker is indifferent between the two prospects "Wildlife – High Tourism" and "No Wildlife–High Tourism", as they product the same value, V1. He is also indifferent between "Wildlife–Low Tourism" and "No Wildlife–Low Tourism", as he values them both at V2. Consequently, wildlife does not play a role in the valuation of the prospects. It is an indirect value. Therefore, this decision maker is indifferent between any two prospects having identical values of the direct value attributes, even if they have different indirect values. The characterization of prospects by the second attribute, Wildlife, in this example, does not affect the preference ordering of the prospects. In contrast, consider a naturist who cares only about the welfare of African wildlife, and is indifferent to the presence of tourists. The environmentalist places a direct value on Wildlife, but not on Tourism. However, this hotel owner believes that tourism would provide funding to preserve animal habitat and defend animals against poachers, and therefore places an indirect value on tourism. Once again, if new information showed that there was no correlation between Tourism and Wildlife, then tourism would no longer be an indirect value.

III. Mixing Direct and Indirect values in Objective Functions

The concepts of direct and indirect values can considerably simplify the formulation and solution of decision problems. While there are many features of a decision that a decision maker might care about, we often identify only a few direct value attributes and recognize other factors as indirect. To order deterministic prospects, we need only consider the levels of their direct value attributes. Two prospects having different indirect values but the same direct values would have the same preference. This implies that the ordering of deterministic prospects should depend only on the direct values. Unfortunately, there is major confusion about this point particularly when direct and indirect values are mixed into some additive objective function.

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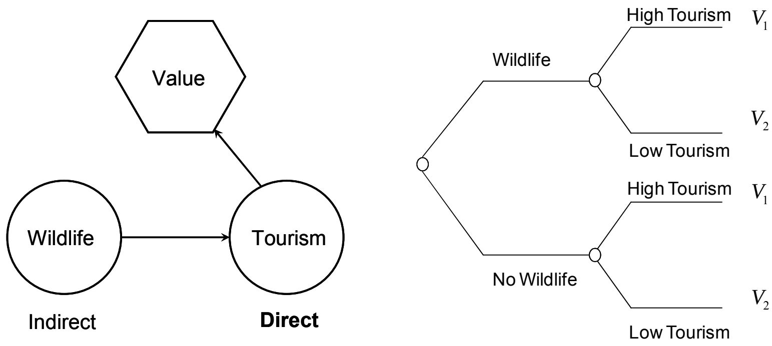

Fig. 1 Direct value attribute for tourism

When a profit maximizing firm thinks about the design of an engineering product, the following factors are usually considered.

a) Quality,
b) Safety,
c) Obeying the Law (Legal),
d) Maximizing Shareholder Return ($),
e) Lie (Ethics).

In many instances, a manager advocates the importance of quality, but the quantification of the value of achieving quality in comparison to the expense of achieving it is seldom provided. One might ask, "If we could maximize shareholder value by selling lower quality products, would not we have a fiduciary responsibility to do it?" for a profit-maximizing firm, the answer would be positive. For a profit maximizing firm, quality might not be a direct value attribute in the first place. Quality is a means for achieving higher profit by selling more products at a given price. The higher the quality, the more likely it is that the demand for the product, and the sales, will be higher, but the direct value attributes are money (total shareholder return) and possibly safety (lives/injuries saved in the process).

There are many ways that can be used to identify whether an attribute is a direct value attribute or an indirect value in a conversation with decision makers. One way is to ask "why do you care about this?" For example, why do we care about quality? People will reply "because it leads to higher demand" and then you ask "but why do you care about higher demand?" and the response would ultimately be "to make more money". These types of questions identify whether a factor of concern is a direct or an indirect value immediately.

Another method to identify direct value attributes is to ask "if you knew that the levels of other attributes were fixed regardless of what you do; would you still care about this attribute?" For example, if the organization were guaranteed a fixed level of profit no matter what the quality of the product were, would they still care about improving quality? The answer would most likely be "No" and so quality would be an indirect value.

Another common error with formulating preferences is that decision makers usually combine direct and indirect values using some weighted combination that is usually additive or multiplicative. This usually involves what is referred to as "importance weights" and the "weight and rate" scoring system.

$$
\begin{aligned}
&P(Quality, Safety, Legal, \$, Ethics) = \\
&w_1 Quality + w_2 Safety + w_3 Legal + \\
&w_4 Shareholder\ Return + w_5 Ethics
\end{aligned}
$$

or like this

$$
\begin{aligned}
&P(Quality, Safety, Legal, \$, Ethics) = \\
&Quality^{w_1} \times Safety^{w_2} \times Legal^{w_3} \times \\
&Shareholder\ Return^{w_4} \times Ethics^{w_5}
\end{aligned}
$$

There is no reason why a preference function should be additive although this is widely used without appropriate verification.

Another common problem is the arbitrariness of scales. For example, safety needs to be clarified and not just assigned some arbitrary scale. When formulating the problem, try to think of something meaningful. Is it the number of lives saved per year? What do we mean by "saved"? Is it the decrease in the number of accidents? This latter definition would also require clarity such as "what counts as an accident and what does not?"

Legal also needs to be specified. It would not be appropriate as an attribute in this setting. Does the company want to avoid anything illegal? If so, then it is a matter of removing any illegal alternatives from consideration. The company might also feel that an alternative is border line and could be interpreted either way, and so they might want to consider the costs associated with legal time that would explain any legal issues if a problem arose. The company would then need to consider the uncertainties associated with any legal pursuits. Ultimately it might translate into cost. Presenting "Legal" alone and asking people to assign some arbitrary scale would be an arbitrary way of handling this problem.

Ethics is also an interesting factor. Once again, if the company has some ethical dilemmas with some of the alternatives it is considering, and if it chooses to avoid such alternatives based on ethical issues, then it should simply remove the alternatives from consideration instead of including what is ethical as a direct value attribute, and trying to assign some scale to it. Shareholder return needs further clarification. Is it the return on the investment measured as a percentage or is it the net present shareholder value? Ratios (such as return) are not appropriate measures to include as direct value attributes.

A first step in the direction of improving the additive and multiplicative functions above is to remove the indirect value attributes and present them on meaningful scales. When you are set on the attributes, and are clear about the direct and indirect values, you still need to think about the actual formula for determining the preferences more clearly: What are the weights in the first two expressions above? Why do we have weights in the first place? What do they mean? How do we assign them? What trade-offs are implied by assuming an additive or a multiplicative functional form? Is there another form that should be used? Unless we are clear about the interpretations of what we are asking others, we will be on a wrong track from the start before we even conduct any analysis.

IV. Using Meaningful and Measurable Attributes

When thinking about the attributes that comprise your preference for a prospect, it is good practice to use attributes that have a meaningful and measurable scale and ones that have no ambiguity about them. Otherwise, different people will have different interpretations for the magnitude of each attribute. For example, an attribute like "*complexity*" in the design of an engineering system might not be easily interpreted, not to mention it is not even a direct value attribute in the first place. For example, it might be that the real issue here is whether a company will be able to achieve technical success for launch and so there is a need to capture the probability of success at a given plant for expected utility calculations, but the prospect itself is characterized by whether or not technical success has been achieved. This is a big difference in thinking from including an arbitrary attribute like "*complexity*"; giving it an arbitrary scale, and then combining it into some arbitrary weighted formula to determine preferences. When an attribute has not been clearly defined, it is usually a result of a lack of clear thinking or, as we shall see in the next section, the absence of some clear structural model that defines the attribute in terms of some other components. Even if some physical structural model does not exist, we might still be able to define preference for attributes in terms of clear components, as we illustrate below.

A. Example: Measurable Attributes for a Seat in the Movie Theatre or a Concert

Think about the attributes that contribute to your preference for a seat in the movie theatre. What would make you prefer one seat over the other? It is difficult to answer this question without a decision context. For example, it might be that the person (or group of people) who are at the movie theatre are not actually interested in the movie in the first place. But with all else constant, suppose you were going alone to the theatre, what factors would lead to your preference for one seat over another for a given movie?

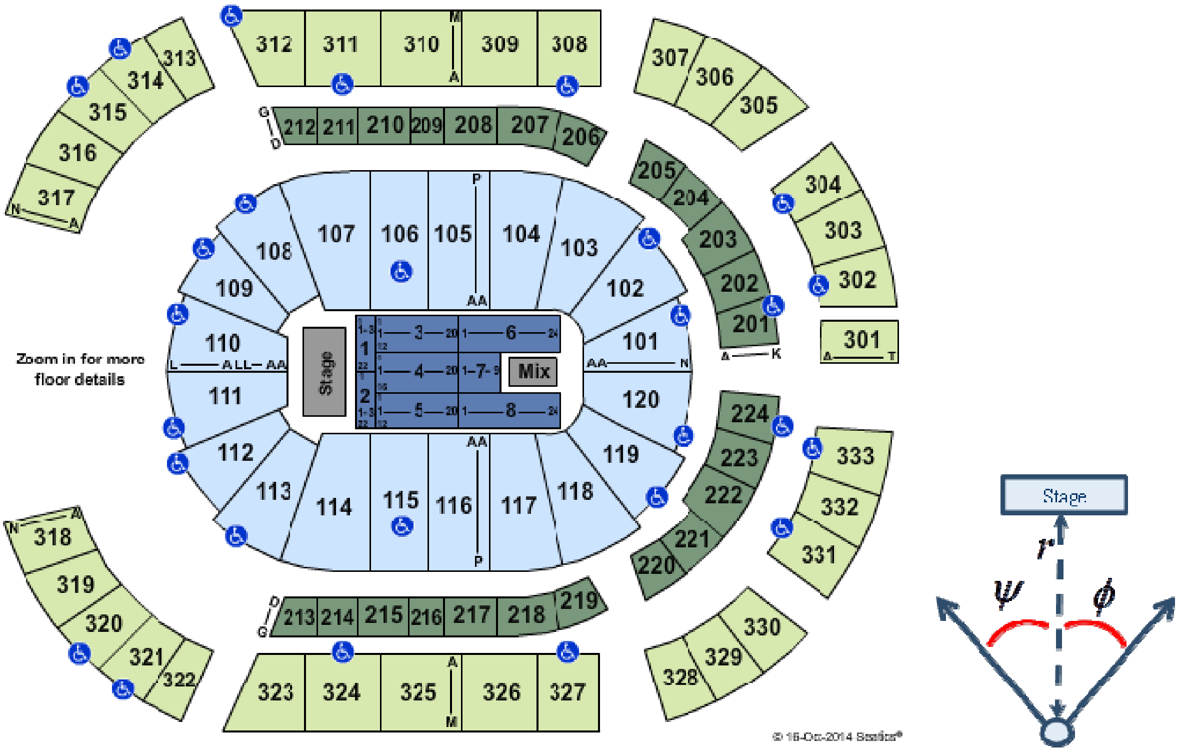

Fig. 2 Layout for seats in a theatre (From Nashville Arena Web site [21])

One factor that could affect your experience is the view, but simply stating “view” is by itself not a clear specification, and assigning an arbitrary score from 0 to 10 (0 being worst and 10 being best) is arbitrary and could be a recipe for disaster.

We can further decompose “view” into other components that are meaningful. One component, for example, could be the radial distance from the screen (or stage). The distance is clear regardless of the units you use. There is no ambiguity about a radial distance of 12 feet, for example. In thinking about your preference for the radial distance, you might not want a seat that is too close to the screen or one that is too far, and so you might have a peak in your preferences at some radial distance: there might be an optimal radial distance below which and above which your preference would decrease.

Another component that could contribute to the “view” is the symmetry by which you view the screen (or stage). You might prefer to be centered. This can be modeled by the angle from the line perpendicular to the screen to your location. Fig. 2 presents a schematic view of a layout of a theatre.

Another consideration could be the “inconvenience” incurred if you have to cross many people to get to your seat. This attribute is not immediately measurable, and so you might interpret it in terms of the number of seats you have to cross, or even as a cost for every seat you would have to cross to get to your seat.

Other attributes might also be involved in this decision, and pertain to a particular theatre, such as sound. For example, if you knew the location of the speakers, you might prefer a seat that is within some radial distance from the speakers, or one that is not too close and not too far.

Now, we have considered three attributes that are clearly defined in terms of other factors: view, convenience of getting to your seat, and quality of the sound. You can continue to model certain aspects of the prospect of a seat until the characterization will contribute very little to your deterministic preference, or that the costs are so small compared to the modeling effort.

We have identified several factors contributing to our preference for the seat, and have formulated them in a meaningful way.

V. Using Structural Models

We have discussed how to think about your preference for a seat in a movie theatre using clear and meaningful factors without having a specified domain-knowledge relationship. In this chapter, we illustrate how structural models can also help us think about our preferences.

Suppose you are interested in the height of a projectile (such as when viewing fireworks from a distance). The projectile is projected vertically at an initial speed u under the force of gravity, g. Ignoring friction, the vertical elevation of this projectile at any time t is given by the formula

$$y = ut - \frac{1}{2} g t^2$$

This logical relationship has decomposed the direct value attribute of height into two other factors, launch speed and time in orbit, and so we may write for some function, f, the vertical distance as

$$y = f(u,t)$$

Now you can think in terms of speed of launch and time in orbit to compare different speeds. You can also use this relation to design a better height for the projectile at a given time, and what the optimal view would be. It would be double counting to think about those attributes as three independent attributes y, u, t using some arbitrary preference function if what you really care about is height.

Another example of a structural model is one for energy generation (or dollars from energy generation). There might exist a structural model that decomposes the direct value attribute of energy into sub-factors such as

$$Energy = \frac{1}{2} \times mass \times (velocity)^2$$

In some cases, the power of velocity or some additional scalars, might also be used with the formula, and determined by experimentation. It would lead to inconsistent preferences if you stated your preference for energy but then expressed it differently in terms of mass and velocity if a structural relation exists.

VI. Using Monetary Equivalents

Having thought about the direct value attributes that lead to the characterization of a prospect it is useful to think about reducing the number of attributes used in its characterization to reduce the dimensionality of the problem. One method of reducing the number of attributes is by converting them into monetary equivalents. For example, commute time in a job is by itself an attribute but may be taken into account by converting this time into a dollar amount. Once this is done, it can be added to the salary attribute and it no longer needs to be treated as a separate attribute of value. By converting direct value attributes into dollar equivalents, we can reduce the burden of thinking about multiple attributes in our preference, value, and utility statements.

A. Example: Monetary Equivalents for Some of the Attributes of a Seat in the Movie Theatre

In the movie theatre example, we discussed three attributes: view, convenience of getting to seat, and quality of sound and clarified them in terms of meaningful and measurable attributes. In some cases, we can reduce the number of attributes by converting some of the attributes into dollar equivalents. For example, if we can place a value on every seat needed to be crossed to get to our seat, and if this dollar amount does not depend on the view or the equality of sound, and if we can also express a dollar amount for quality of sound independent of the other attributes, then we can simple add up dollar amounts from the direct values. We do not treat monetary amounts differently.

VII. Understanding the Enterprise Culture

When formulating preferences in an enterprise, many factors might influence the decision making process. Besides decision making for a single decision maker [1], [7]-[10], it is important to understand how a group might think about their preferences either in the form of a group utility function [11], [12] or a partnership [13], and also understand the effects of the various incentive structures on the decision making [14]-[16]. Often a mix of domain knowledge experts about an engineering phenomenon are needed to work with decision analysts to provide models that capture preference structures [17]-[20].

VIII. Conclusion

Before rushing to select the attributes of a decision, it is important to ask the following questions:

1) Have we considered the important attributes? Are they direct or indirect values?

Direct value attributes are what should be used to characterize preference, value, and utility. Indirect value attributes play a role in characterizing the uncertainty about the value obtained by direct value attributes. To help identify the direct value attributes, ask yourself why you care about a particular value? Usually, this process continues until the direct values are identified. Another method is to ask if the levels of other attributes are guaranteed to be fixed, would you still care about this value? If the answer is negative, then this is not a direct value.

2) Are the attributes meaningful and measurable?

Do not use attributes that have arbitrary interpretations like “comfort” and “taste” without clarifying these factors using meaningful measures.

3) Do the chosen attributes have arbitrary constructed scales?

Do not use arbitrary scores, like a scale of 0 to 5, as measures for the attributes if the scale is not meaningful.

4) Can you convert any of the direct value attributes into monetary terms?

If you can convert some of the attributes into monetary equivalents, then go ahead and do it. This will reduce the dimensionality of the problem significantly.

5) Does there exist a structural model than can help you think about your preferences?

If a structural model exists, it is important to incorporate to make sure you are being consistent with your preferences and are avoiding double counting.

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