

A Methodology for Design Decisions using Block Diagrams

Vijitashwa Pandey and Zissimos Mourelatos
Oakland University

ABSTRACT

Our recent work has shown that representation of systems using a reliability block diagram can be used as a decision making tool. In decision making, we called these block diagrams *decision topologies*. In this paper, we generalize the results and show that decision topologies can be used to make many engineering decisions and can in fact replace decision analysis for most decisions. We also provide a meta-proof that the proposed method using decision topologies is entirely consistent with decision analysis at the limit. The main advantages of the method are that (1) it provides a visual representation of a decision situation, (2) it can easily model tradeoffs, (3) it can incorporate binary attributes, (4) it can model preferences with limited information, and (5) it can be used in a low-fidelity sense to quickly make a decision. The method is based on recent developments towards identifying system topologies with limited information and representing a reliability block diagram with linear algebra operations. This paper details the theoretical basis of the proposed method and highlights its importance. An example is used to demonstrate how decision topologies can be used in practice.

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1. INTRODUCTION

There is a consensus that engineering design is a series of decisions made by the stakeholders involved (Lewis et al. 2006). After the seminal work by von Neumann and Morgenstern (1947), many decision making methods have been proposed in the literature that aim to formalize engineering decision making such as weight-and-rate, AHP (Saaty, 1990), fuzzy logic and decision analysis (Howard, 1988). They can be divided into normative (what a decision maker should do) and descriptive (what a decision maker would do). While decision analysis, one of the more famous normative methods, has seen some application in engineering design, widespread use has not occurred. We believe this is because of difficulty in accurate assessment of utility functions particularly when many attributes are present. In this paper, we propose a visual method which utilizes *decision topologies* (DT) in making decisions. We show using a meta-level proof that the method is consistent with decision analysis, and also provides some advantages over it.

1.1. Why Do We Need Another Method?

Despite the general consensus that engineering design is a decision making process (Hazelrigg, 1988), the widespread use of decision making tools is impeded by the complexity of these tools. Most engineers are not trained in decision analysis and are therefore, used to implementing "best

practices" when it comes to making decisions. Even when a facilitator (an individual helping a designer make a decision) attempts to elicit the DM's preferences, errors can be made. These errors may result from problems associated with stated and revealed preferences (Train, 2003). Many times facilitators overwhelm the decision maker with questions, particularly when the DM is not entirely comfortable giving responses to lottery questions. The objective of this paper to present a method that can improve the applicability of decision making tools by making them intuitive and visual. The main advantages of the proposed 'decision topologies' (DT) method are that (1) it provides a visual representation of a decision situation, (2) it can easily model tradeoffs, (3) it can incorporate binary attributes, (4) it can model preferences with limited information, and (5) it can be used in a low-fidelity sense to quickly make a decision. The method is based on recent developments towards identifying system topologies with limited information (Pandey and Mourelatos, 2012b) and evaluating a reliability block diagram using linear algebra operations (Pandey et al., 2012).

2. DECISION TOPOLOGIES

In this section, we present a simple example which will clarify the advantages of DT over DA. The example is taken from Pandey and Mourelatos (2012a). Consider Emily, who is purchasing a used car. The attributes she considers are fuel economy M in miles per gallon (mpg), acceleration, A , in

seconds for 0-60 mph, roominess R in cu. ft., price P in dollars, luxury L (acceptable/unacceptable) and color C (acceptable/unacceptable). Note that some attributes such as luxury and color are not easy to define mathematically. They are subjective because they are, by definition, perception based. One example of how her preferences can be depicted using a reliability block diagram is shown in [Figure 1](#).

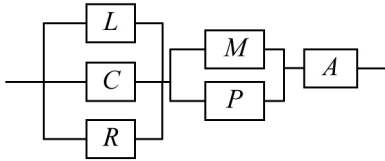


Figure 1. Reliability block diagram for the system topology in the car buying example

We interpret the reliability block diagram using simple reliability engineering principles ([Kapur and Lamberson, 1977](#)). Emily will not buy the car if it does not have the desired level of acceleration, which explains why the acceleration attribute A is in series with the other blocks. She will buy an expensive car if it gives good mileage or will prefer a cheaper car for low mileage. Therefore, the mileage M and price P attributes are connected in parallel. Furthermore, the subjective attributes provide redundancy for each other. For example, she will buy the color she does not prefer while buying a luxury car with enough room. This implies that the color C , luxury L and roominess R attributes are connected in parallel. It is possible that the two customers have different preferences for each attribute but agree to the same topology. Because the reliability block diagram is used in a decision making sense here, we call it a *Decision Topology* (DT). The visual aspects of how DTs can help decision making are immediately clear.

2.1. Decision Analysis

In decision analysis, we define a multiattribute utility function U over the attributes which measures the desirability of different attribute combinations. Therefore, a multiattribute utility function (MAUT) allows ranking of alternatives involving multiple attributes. A general form of a MAUT is given by $U(y_1, \dots, y_n)$ where y_i 's are the individual attributes. Many times, to ease the assessment of MAUTs, one can construct them from single attribute utility functions, if certain independence conditions are met ([Clemen, 1997](#)). This construction is preferred in literature, despite the strong underlying assumptions because single attribute utility functions are comparatively easier to acquire. The multiplicative form of the multiattribute function ([Keeney and Raiffa, 1994](#)) is provided by:

$$U = \frac{1}{K} \left(\prod_{i=1}^n (Kk_i U_i(y_i) + 1) - 1 \right). \quad (1)$$

In this case, multiattribute utility assessment indicates assessment of the individual utility functions U_i and the scaling constants k_i which measure the relative disinclination of a decision maker to tradeoff a particular attribute. In the next section we present how decision topologies are consistent with decision analysis.

2.2. A Meta-Proof of Consistency with Decision Analysis

In this section, we present a meta-proof showing that in the limit, decision topologies provide the same answer to a decision problem as normative decision analysis. Assume that we have n attributes, $y_1 \dots y_n$ and for each attribute the upper and lower limits (range of negotiability) is given by $y_i^{\min}$ and $y_i^{\max}$, where i is the attribute in question. For each attribute, within the range of negotiability, we define a partition $y_i^{\min} = y_i^0 < y_i^1 < \dots < y_i^{m_i} = y_i^{\max}$. Without loss of generality, we assume that utility is monotonically increasing in each attribute, resulting in:

$$U(y_1^{\text{fixed}}, \dots, y_i^0, \dots, y_n^{\text{fixed}}) < U(y_1^{\text{fixed}}, \dots, y_i^1, \dots, y_n^{\text{fixed}}) < \dots < U(y_1^{\text{fixed}}, \dots, y_i^{m_i}, \dots, y_n^{\text{fixed}}) \quad \forall i \quad (2)$$

As shown in [Table 1](#), there are four conditions we want the score S from a decision topology to follow.

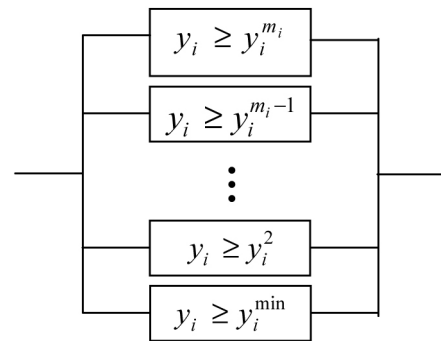
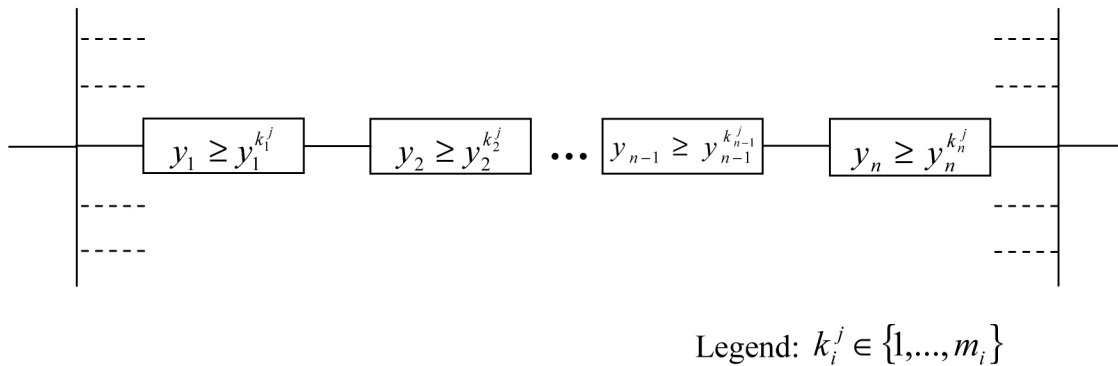


Figure 2. A decision topology for a single attribute (superscript is not an exponent)

Let us start with the single attribute case. We can represent the decision topology associated with an attribute visually as shown in [Figure 2](#). Each block tests the binary condition that an attribute is greater than one partition y_i^j of the attribute. Now the *raw* score for an attribute level y_i is equal to the number of paths from right to left (or left to right) through the blocks that are active. For example when $y_i \geq y_i^{\max}$ all blocks will be active because all inequalities are satisfied. Similarly when $y_i < y_i^{\min}$ none of the blocks will be active. For intermediate values of y_i , a number less

Table 1. Requirements of decision topologies for consistency with decision analysis

Requirement	Mathematical statement
Each attribute has the lowest acceptable limit. If any of the attributes is strictly below its minimum acceptable limit, the utility is zero regardless of the value of the other attributes.	$S(y_1, \dots, y_i < y_i^{\min}, \dots, y_n) = 0$ for any i .
If all attributes are equal to their minimum acceptable limits, the utility is zero.	$S(y_1 = y_1^{\min}, \dots, y_n = y_n^{\min}) = 0$
If all attributes are equal or greater than their maximum desirable limits, the utility is equal to one.	$S(y_1 \geq y_1^{\max}, \dots, y_n \geq y_n^{\max}) = 1$
When all attributes are strictly within their ranges of negotiability, the score provided by a DT should be the same as the utility for the design.	$S(y_i \in (y_i^{\min}, y_i^{\max}) \forall i) = U(y_i \in (y_i^{\min}, y_i^{\max}) \forall i)$

**Figure 3. Decision topology for multiattribute case (only one row shown)**

than m_i will be active. Since utility functions are conventionally constrained to lie between 0 and 1, we can divide the score of an attribute level by m_i^1 to get a *normalized* score which we simply refer to as score S . Notice that on initial thought, it seems that this will make the score linear in attribute level (akin to a linear utility function) but this is not true. It depends on the partitioning of the attributes to draw the topology, which may or may not be uniform. In fact, if the density of partitions around a particular value of y_i is equal to the derivative of the utility function at y_i , the normalized score will be equal to the utility value. This is guaranteed if $m_i \rightarrow \infty$.

2.2.1. Tradeoffs

The multiattribute case is less straightforward than the single attribute case. As before, each attribute is partitioned within its range of negotiability. The partition of each

attribute has a block of the form $\{y_i \geq y_i^j\}$ associated with it. Since we have m_i blocks for an attribute i , the total number

of block combinations is equal to $\prod_{i=1}^n m_i$. The most intuitive way to draw the decision topology in that case is to use a tuple of blocks in each row of the decision topology as shown in [Figure 3](#). In the end, the decision topology will have

$\prod_{i=1}^n m_i$ rows in parallel. The score from such a topology mimics the multiattribute utility function and is monotonic in each attribute, as expected. Moreover

$$S(y_1 \geq y_1^{\max}, \dots, y_n \geq y_n^{\max}) = 1 \quad \text{and}$$

$$S(y_1 = y_1^{\min}, \dots, y_n = y_n^{\min}) = 0.$$

¹It is possible for a decision topology that the score is greater than m_i when all blocks are active. In such cases, the normalization will be done by that score. Also, since utility functions are invariant under positive linear transformations, this normalization is not necessary except when following the convention that utility is scaled between 0 and 1.