Resources and Background Documents

2017 TEAMS Design/Build Challenge

Decision Making Introduction

Scientific discoveries are based upon observations of how systems function and interact with each other. At each and every point in the discovery process, engineers and scientists make decisions about which of the many observations have meaning and interpret their likely impact on the system they are studying. When an observation leads to new questions about the nature of the system, new tools are often required in order for us to gain a deeper understanding. Developing these new tools requires additional decisions to be made.

Whether it's developing new and better tools to image the inner workings of the human brain, pioneer space exploration, or clarify the most fundamental laws of nature, these tools will be developed through decision making. As the tools require more complexity, scientists and engineers will rely upon decision making frameworks to help inform their paths to discovery and to record their journey.

How can engineers help? Your team will be challenged to understand how decision making frameworks inform the engineering design process. You will be asked to use a decision making framework to solve an engineering problem.

DESIGN CHALLENGE DECISION MAKING

Background

How do you make a decision? If you were given the option of eating a Snickers bar or a Fuji apple, which one would you choose? Your choice will likely be made within less than a second. Your brain selected the answer automatically and the decision was likely very straightforward for you.

What actually happened was far more complicated for even such a simple question. Most likely, you immediately considered your two options and benchmarked them against a given set of criteria you use to decide on the food you like to eat. These criteria helped you make your decision, whether you knew it or not. Some of the criteria your mind automatically screened may be minor to your decision (i.e. how hungry you were, what time of day it is, and the type of apple). However, some of the criteria may have been major influences as to the outcome of your decision (i.e. whether or not you have a peanut allergy). In the case of the Snickers bar versus apple decision, not only did you screen the many different potential criteria but you also weighted their importance in making your decision. And by now it probably would not surprise you that another person may have selected differently based upon the criteria they used to decide on their food choices.

Not all decisions are as simple as the food you prefer to eat or decisions between only two options. However, as the complexity of the decision increases, the process of selecting a decision based upon established criteria still occurs. A decision matrix is a tool engineers may rely on to help clarify a decision between two or more alternatives. A decision matrix is an algorithm used to clarify the best option given an established set of criteria.

DECISION MATRIX

The Math Behind a Decision Matrix

A decision matrix ranks two or more alternatives against each other by assigning points to each alternative based upon a given set of criteria. Note that it is not necessary to understand *how* the decision matrix works; rather, it is important to understand which criteria are most important.

The alternative that receives the highest total number of points is the best choice. The three equations used in the decision matrix are presented as Equations 1, 2, and 3 in the text that follows.

Equation 1 provides the formula for determining the total number of points for each alternative (*i*): the total points is the sum of the points earned for each criteria.

$$P_t = \sum_{j=1}^{m} P_{ij} W_j \qquad \text{Equation 1}$$

Where P_t = total points given to each alternative i
P_{ij} = rating that alternative i receives for a specific criteria j
W_j = weighting factor for that alternative
m = the number of alternatives

How do we calculate the number of points for each criteria? We need to know whether it's better to have a higher number (strength) or a lower number (cost), and we need to know the minimum value and maximum value for each criteria. The number of points assigned to the alternative for a given criteria *if lower is better* is given in Equation 2.

$$P_{ij} = \frac{C_{jmax} - C_{ij}}{C_{jmax} - C_{jmin}} \qquad \text{Equation 2}$$

Where P_{ij} = points that alternative I receives for a specific criteria j
C_{ij} = value of alternative
C_{jmax} = maximum value of criteria range
C_{jmin} = minimum value of criteria range

The amount of points assigned to the alternative for a given criteria *if higher is better* is given in Equation 3.

$$P_{ij} = \frac{C_{ij} - C_{jmin}}{C_{jmax} - C_{jmin}} \qquad \text{Equation 3}$$

Where P_{ij} = points that alternative I receives for a specific criteria j
C_{ij} = value of alternative
C_{jmaxj} = maximum value of criteria range
C_{jmin} = minimum value of criteria range

The math and explanation may be confusing; the concepts are shown in an example.

DECISION MATRIX
Illustrative Example

You are going to buy a new laptop computer and have narrowed your selection based upon your preferences to three different computers. Rather than choosing one at random, using a decision matrix can help make the decision.

Let's consider three criteria that are typically important.
These criteria include:

cost   weight   screen size

If each criterion is equally important, all will have an equal weighting as we make our decision (33.33%). However, for this illustrative example, let's consider cost as most important with a 65% weighting, screen size as second most important with a 25% weighting, and weight (of least importance) with a 10% weighting in the decision matrix. By assigning weights to each criterion, we have arranged for one criterion (cost) to have the most impact on our decision. The other criteria are important in our decision process, but not as important as cost.

Additionally, when we examine each criterion we can also specify a range and a direction to help clarify our decision. For instance, we may be willing to pay between $400 and $2000 for a computer (the range we will consider as a minimum and maximum value) and in our decision, the lower the value the better (the direction). Because lower is better, we use Equation 2 to determine the points for this particular criterion. For weight, we may be willing to carry between 5 and 8 pounds, with the lighter computer being favored. Again, because a lower value is better, Equation 2 (as opposed to Equation 3) will be used to assess points for weight. For screen size, the largest screen size is preferred, but we may not have a range in mind. In this case, we are interested in a higher value being preferable, so we will use Equation 3 to determine points for this criterion.

Now that our criteria are set, let's look at the alternatives. The following table lists the alternative along with its characteristics. The column headings also include the range and direction for each criterion.

Alternative	Cost ($400-$2000, lower is better)	Weight (5 – 8 lbs, lower is better)	Screen Size (range not given, bigger is better)
Computer 1	$1200	7 lbs	21 inches
Computer 2	$1650	6.5 lbs	17 inches
Computer 3	$800	5.8 lbs	18 inches

Let's examine cost a bit further in order to determine how points are calculated. Because lower is better, we will use Equation 2 to determine the points each alternative computer earns for cost.

For computer 1, Equation 2 produces the following point value:

$$P_{1,cost} = \frac{C_{jmax} - C_{ij}}{C_{jmax} - C_{jmin}} = \frac{\$2000 - \$1200}{\$2000 - \$400} = 0.5$$

We can apply this same equation (Equation 2) to determine point values for Computers 1, 2, and 3 for both the cost criterion and the weight criterion. For weight, note that the max and min values are 8 lbs and 5 lbs, respectively.

For screen size, we will need to use Equation 3, because the larger size (higher value) is preferred. Because no range was specified, we will also just use the range of values for the different options (max = 21 and min = 17). For computer 1, equation 3 produces the following point value.

$$P_{ij} = \frac{C_{ij} - C_{jmin}}{C_{jmax} - C_{jmin}} = \frac{21 - 17}{21 - 17} = 1$$

We then repeat equation 3 for each other computer alternative.

When we fill in all of the point values, we get the following matrix. When you performed the calculations on your own, did you (or your group) get the same?

Alternative	Cost Points	Weight Points	Screen Size Points	**Total Points**
Computer 1	0.5	0.33	1	1.83
Computer 2	0.22	0.5	0	0.72
Computer 3	0.75	0.73	0.25	1.73

The total points for a given alternative is a summation of all the points earned across the respective criteria. In the above table, the points represent equal weighting. With equal weighting, the best option (highest points) is Computer 1, followed closely by Computer 3, with Computer 2 coming in a distant third.

However, for our decision matrix, we favored cost (65%), screen size (25%) and weight (10%) in our specified weighting. When we consider the weighting, we will apply the percent weighting to each of the points. For computer 1, the weighting changes the point values according to:

Alternative	65% weighting Cost Points	10% weighting Weight Points	25% weighting Screen Size Points	Total Points
Computer 1	0.5*0.65 = 0.325	0.33*0.1 = 0.033	1*0.25	0.608

When we adjust all of the criteria for their weighting, then the matrix becomes:

Alternative	Cost Points	Weight Points	Screen Size Points	Total Points
Computer 1	0.325	0.033	0.25	0.608
Computer 2	0.142	0.050	0.00	0.192
Computer 3	0.4875	0.073	0.063	0.623

When all of the weighting is considered, look at what happens. Now Computer 3 becomes your best choice, closely followed by Computer 1, with Computer 2 still a distant third.

DECISION MATRIX

Sample Problem

While there are many different criteria we could have selected, we limited our example to three criteria to make the example easier to follow. What happens now if you decide to include processer speed and hard drive storage space as two additional evaluation criteria? Note that the weighting now changes because of the additional criteria. Given the following set of characteristics for a given criterion, which option is best now?

	Cost	Weight	Screen Size (in)	Processor speed (Ghz)	Hard Drive Storage (GB)
Range	$400-$2000	5-8 lbs	Not given	Not given	500-1000
Direction	lower	lower	higher	higher	lower
Weighting	45%	5%	5%	30%	15%
Computer 1	$1200	7 lbs	21	3.8	600
Computer 2	$1650	6.5 lbs	17	3.4	750
Computer 3	$800	5.8 lbs	18	2.5	810

Solution

Alternative	Cost Points	Weight Points	Screen Size Points	Processor speed Points	Hard Drive Storage Points	Total Points
Computer 1	0.225	0.017	0.050	0.300	0.120	0.712
Computer 2	0.098	0.025	0.000	0.208	0.075	0.406
Computer 3	0.338	0.037	0.013	0.000	0.057	0.444

Here, Computer 1 is your best choice!