Module Purpose: Analytical Hierarchy Process

- To understand the basic steps in the decision making process.
- To introduce the use and importance of Figures of Merit (FOM); provide example FOMs.
- To introduce the Analytical Hierarchy Process (AHP) as a sample method for selecting the best alternative.
- To discuss the pros and cons of using AHP, and consider an example application.
Importance of the Early Decision Making Process

- Choosing the architecture, mission mode, or concept of operations is one of the most important decisions that is made early in the design process.
- Presented with a situation where a decision must be made, the decision maker must always choose based on some implicit or explicit evaluation criteria.
- Therefore, consciously and deliberately choosing the criteria is of vital importance in the decision making process.

Basic Steps in the Decision Making Process

1. Establish evaluation criteria
2. Establish relative importance of evaluation criteria
3. Develop alternative concepts that meet objectives and top-level requirements
4. Evaluate alternatives relative to the established evaluation criteria
5. The alternative that best satisfies the evaluation criteria represents the tentative concept choice
6. Tentative concept choice is evaluated in more detail to identify any unforeseen drawbacks
7. In light of the information gained from the more detailed study, the decision is finalized or the decision maker returns to Step 3
**Figure of Merit (FOM) – 1 of 2**

- **Figure of Merit (FOM):** A metric by which a stakeholder’s expectations will be judged in assessing satisfaction with a product or system.

- FOMs are deemed to be critical to both the acceptability of the product by the stakeholder and to the operational usage of the product.

- A good FOM has the following properties
  - Independent of any particular solution
  - Simple to state and unambiguous
  - Easy to measure

**Figure of Merit (FOM) – 2 of 2**

- Typical uses of FOMs include:
  - Determine how concepts meet high-level requirements
  - Compare and rank alternative concepts and solutions
  - Assess the relative sensitivity of the mission to key operational assumptions and performance parameters

- FOMs are frequently referred to as Measures of Effectiveness (MOEs) and/or Measures of Performance (MOPs) by the Department of Defense
**FOM Example – 2007 NASA Mars Design Reference Mission**

Example FOMs used to evaluate Mars Surface Power System concepts:

- Total landed mass (quantitative)
- Autonomous deployment complexity (qualitative)
- Power level stability (qualitative)
- Sensitivity to dust (qualitative)
- Reliability (quantitative)
- Ability to repair (qualitative)
- Increase in crew radiation exposure (qualitative)
- Latitude flexibility (quantitative)
- Scalability (quantitative)
- Similarity to lunar system (qualitative)
- Cost through first mission (quantitative)

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**Picking the Best Alternative**

- In general, more than one criterion will be of importance and various criteria frequently conflict with one another

- If multiple criteria exist, preferences between these criteria must be established, making the resulting decision inherently subjective

- A number of methods exist for selecting the best alternative
  - Overall Evaluation Criterion (OEC) and Cost-Benefit Analysis
  - Pugh Matrices
  - Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
  - Analytical Hierarchy Process (AHP)
Analytical Hierarchy Process

- Analytical Hierarchy Process (AHP)
  - Determines “best” through a series of pair-wise comparisons
  - Can be used to determine attribute weightings as well as alternative scores

- Steps in the AHP Process (paraphrased from the NASA Systems Engineering Handbook)
  1. Describe in summary form the alternatives under consideration
  2. Generate high-level Figures of Merit
  3. Decompose high-level FoMs into a hierarchy of evaluation attributes
  4. Determine relative importance of FoMs through prioritization matrix and pairwise comparisons
  5. Make pairwise comparisons of the alternatives with respect to each of the FoMs
  6. Iterate until consensus is reached

Using AHP to Score Alternatives

AHP Computational Procedure:
1. Populate AHP matrix by defining relative preferences on a 1-9 scale
2. Sum each column
3. Normalize each column by its sum
4. Average each row to determine the final score for each concept

AHP Weighting Scale

A number greater than 1 indicates that you prefer the alternative in the row over the alternative in the column.
Using AHP to Rank Concepts

Characteristics of interest: 1, 2, …, i
Concepts: 1, 2, …, j

\[ \text{score}_j = \sum_{n=1}^{i} w_n s_{nj} \]

A little bit of controversy…

It may be a sign that consensus has not been reached when something like the following sequence of paper titles is seen in the literature*:

Some Comments on the Analytic Hierarchy Process

R. D. HOLDER
Consultancy Group, SD-Scion UK Limited, London

RESPONSE TO HOLDER’S COMMENTS ON THE ANALYTIC HIERARCHY PROCESS

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As with any analytical tool, there are criticisms of AHP

- Assumes (and imposes) hierarchy among alternatives
- Some suggest that the scale used for comparisons should be multiplicative or exponential instead of linear
- AHP can experience a phenomenon known as rank reversal
- The responses to the “neutral” to “strongly prefer” scale are highly subjective and implicitly (or explicitly) require the user to establish a reference point on the scale – the choice of this scale may affect the results

Additional Thoughts on AHP – 1 of 3

- AHP is a commonly used and widely accepted decision making tool
- AHP is uniquely equipped to compare quantitative and qualitative criteria in a common framework
- It only makes sense to compare options or alternative concepts that meet all the requirements (i.e. only consider feasible alternatives)
- Ranking of FOMs or objectives through the prioritization matrix is perhaps the greatest strength of AHP – some suggest that AHP should only be used for this purpose
Additional Thoughts on AHP – 2 of 3

- A higher score in the AHP matrix represents *preference* – a frequent mistake is to assign a higher score to the alternative with the higher FOM value. This means, for example, that a cheaper alternative (lower cost number) should be given a higher score if minimizing cost is the criteria.

- AHP should only be used to compare alternatives to a set of FOMs where a spectrum of preference exists. If it is simply a property that must be met in a yes/no fashion, there is no need to use AHP for this metric.

Additional Thoughts on AHP – 3 of 3

- Clearly, AHP is not appropriate for all decisions and comparisons. Take, for example, more detailed technical problems – in these cases you often rely on engineering judgment and experience rather than a formalized systems engineering tool to make the decision.

- Be aware of how to use AHP correctly – and be able to identify times when it is being used incorrectly.

- In many cases, the value of AHP (and other system engineering tools) is not the final product, but the insight gained along the way.
**Pause and Learn Opportunity**

Walk through the AHP example (AHP_example.xls). The example is for a student to select a graduate school, defining 4 schools and 5 attributes of interest. The example file also shows a spider plot - a visual way to represent the results of the AHP.

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**Decisions, Decisions, Decisions…**

Dear Sir:

In the affair of so much importance to you, where in you ask my advice, I cannot, for want of sufficient premises, advise you what to determine, but if you please I will tell you how. When those difficult cases occur, they are difficult, chiefly because while we have them under consideration, all the reasons pro and con are not present to the mind at the same time; but sometimes one set present themselves, and at other times another, the first being out of sight. Hence the various purposes or information that alternatively prevail, and the uncertainty that perplexes us. To get over this, my way is to divide a sheet of paper by a line into two columns; writing over the one Pro, and over the other Con. Then, during three or four days consideration, I put down under the different heads short hints of the different motives, that at different times occur to me, for or against the measure. When I have thus got them all together in one view, I endeavor to estimate their respective weights; and when I find two, one on each side, that seem equal, I strike them both out. If I find a reason pro equal to some two reasons con, I strike out the three. If I judge some two reasons con, equal to three reasons pro, I strike out the five; and thus proceeding I find at length where the balance lies; and if, after a day or two of further consideration, nothing new that is of importance occurs on either side, I come to a determination accordingly. And, though the weight of the reasons cannot be taken with the precision of algebraic quantities, yet when each is thus considered, separately and comparatively, and the whole lies before me, I think I can judge better, and am less liable to make a rash step, and in fact I have found great advantage from this kind of equation, and what might be called moral or prudential algebra. Wishing sincerely that you may determine for the best, I am ever, my dear friend, yours most affectionately.  

—Benjamin Franklin

Many decisions are made early in the project life cycle. The decision maker must always choose based on some implicit or explicit evaluation criteria.

The basic steps in the decision making process include:
1. Establish evaluation criteria
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Figures of Merit (FOM) is a metric by which a stakeholder’s expectations will be judged in assessing satisfaction with a product or system.

The Analytical Hierarchy Process (AHP) is a methodology that determines “best” through a series of pair-wise comparisons. It can be used to determine attribute weightings as well as alternative scores.
- One of the benefits of AHP is the use of a standardized process by which to compare alternatives. It can be used with both quantitative and qualitative data.