Decision Tools

Pugh's Concept Selection

Pugh's Concept Selection

- Peer concept – rate alternatives against a peer (datum)

- Used after initial House of Quality developed
  - Subsequent use at each subsystem level

Pugh's Procedure

1) It is essential that all of the ideas and embryonic solutions are generated against the background of the requirements and constraints of the project – that is, they are projected solutions to the same problem having the same requirements and constraints

2) Having established a number of possible solutions to the problem in hand, depict these solutions in sketch form, to the same level of detail in each case

Pugh's Procedure

3) Establish a concept comparison and evaluation matrix, which compares the generated concepts, one with the other, against the criteria for evaluation

4) It is essential that the matrix has all the 'visuals' (sketches) of all concepts incorporated into it, so that the design team can witness the pattern of emergence. In the case of electronic projects, block diagrams or circuits will suffice. For complete clarity, word descriptions should be added

Pugh's Procedure

5) Ensure that the comparison of the different concepts is valid – that is, they are all to the same basis and to the same generic level

6) Choose criteria against which the concepts are to be evaluated. These must be based on the detailed requirements of the project – that is, established before the generation of a solution commences. It is essential that the criteria chosen are unambiguous, understood and accepted by all participants in the evaluation, and written down for future reference

Pugh's Procedure

7) Choose a datum with which all other concepts are to be compared. If a design(s) already exist (s) for the product area under consideration, this must be included in the matrix and used as a useful first datum choice. Where competitive designs do not yet exist and all concepts have been generated internally, the first datum choice should be the one the group thinks intuitively is the 'best'

Pugh's Procedure

8) In considering each concept/criteria against the chosen datum, the following legend should be used:

+ (plus): meaning better than, less than, prone to, easier than, etc., relative to the datum

-(minus): meaning worse than, more expensive than, more difficult to develop than, more complex than, more prone to, harder than, etc., relative to the datum

Where doubt exists as to whether a concept is better or worse than the datum, then use:

S (same): meaning same as datum

Pugh's Procedure

9) Having selected a datum, make an initial comparison of the other concepts using the nomenclature just outlined. This establishes a score pattern in terms of the number of +'s, -'s, and S's achieved relative to the datum. The scores or numbers must not, in any sense, be treated as absolute; they are for guidance only and must NOT be summed algebraically

10) Assess the individual concept scores. Certain concepts will exhibit exceptional strengths, while others will show the converse – that is, weakness

Pugh's Procedure

11) Look at the negatives of the strong concepts – what do you need to do to the design to improve it and reverse the negative? Is it possible at all? If so, in achieving the improvement and reversal, do you in fact reverse one or more of the existing positives? If it is possible to introduce a modified concept into the matrix do so, do NOT just modify the one you have got and leave it there, as you may wish to go back to it later. This expands the matrix

Pugh's Procedure

12) Look at the weak concepts and attack their negatives to see whether they can be improved upon (relative to the datum concept – not to some elusive absolute). If they can be improved and other positives are not reversed in so doing, then introduce the revised concepts into the matrix. Again, this expands the matrix

13) Having carried out steps 11 and 12 rigorously, truly weak concepts should then be eliminated from the matrix. There will be an overall reduction in the matrix size

Pugh's Procedure

14) If a number of strong concepts do not emerge as a result of steps 11-14, then it is usually indicative of one of two things or a mixture of both:

a) The criteria are ambiguous, capable of a variety of interpretations by group members, or critical examination of a suspect criterion will reveal that it already incorporates one or more of the other criteria – the result, confusion. Decompose into more than one criterion

b) Persistence of uniformity of strengths between concepts usually means that one or more concepts are subsets of the others (they are one and the same thing), and the matrix cannot help to make the distinctions where none exists

Pugh's Procedure

15) When one particular concept persists, rerun the matrix using the strongest emergent concept from the first run as datum. Does the pattern persist? If it does, this will confirm the first run. If it does not, then repeat steps 11 and 12 until strong concepts persist

Sample Pugh's

Concept / Criteria	1	2	3	4	5	6	7	8	9	10	11
A	+	–	+	–	+	–	D	–	+	+	+
B	+	S	+	S	–	–		+	–	+	–
C	–	+	–	–	S	S	A	+	S	–	–
D	–	+	+	–	S	+		S	–	–	S
E	+	–	+	–	S	+	T	S	+	+	+
F	–	–	S	+	+	–		+	–	+	S
Σ+	3	2	4	1	2	2	U	3	2	4	2
Σ–	3	3	1	4	1	3		1	3	2	2
ΣS	0	1	1	1	3	1	M		1	0	2

Rating/Weighting Method

Rating/Weighting Method

- Basic matrix
  - Concepts are placed horizontally at top of matrix
  - Criteria for evaluation on left-hand side
- Criteria are placed in order of merit and each is given a weighing factor
  - Based on 1-5 or 1-10 scale
  - The higher the weighting factor, the greater the relative importance of the criteria
  - Order of criteria and values allocated to them are matters of judgment

Rating/Weighting Method

- Alternative concepts are rated in turn against the criteria
  - Allocated a value on a 1-5 or 1-10 scale
  - Concepts that appear to satisfy the criteria best, on a relative basis, are given the highest numbers – again, these are arrived at by judgment
- Criteria weighting values are multiplied by the rating values to give a total score for each alternative
  - Concepts having the highest scores are those that appear to best satisfy the criteria

Rating/Weighting Method

- Main reason for using rating and weighting is that it allows numbers to be allocated to some non-quantifiable parameters – aesthetics, materials compatibility, maintenance, etc. – and thus provides a base to which the various types of criteria can be reduced

Example

Objective	Weight factor	Rating				Weight factor × Rating			
		m/c 1	m/c 2	m/c 3	m/c 4	m/c 1	m/c 2	m/c 3	m/c 4
Make 20 000 brushes per 8-hour shift	4	5	5	0	5	20	20	0	20
End of brush safety	5	0	5	5	5	0	25	25	25
Ease of manufacture of machine	3	4	0	3	4	12	0	9	12
Reliability of operations	5	4	2	4	4	20	10	20	20
Overall size of machine	2	3	4	3	3	6	8	6	6
Cost	3	3	2	3	3	9	6	9	9
Good filament density	4	3	5	5	5	12	20	20	20
				Total		79	89	89	112

Analytical Hierarchy Process (AHP)

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

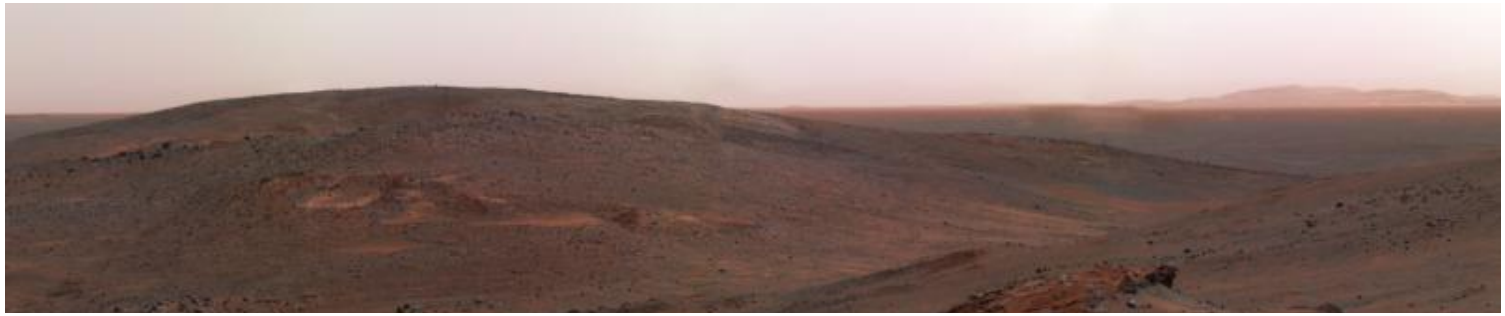
- Typical uses of FOMs include:
  - Determine how concepts meet high-level requirements
  - Compare and rank alternative concepts and solutions
  - Assess the relative sensitivity of the mission to key operational assumptions and performance parameters

- 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)



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

Prioritization Matrix	Attribute #1	Attribute #2	Attribute #3	Attribute #4
Attribute #1	1	3	1/2	8
Attribute #2	1/3	1	1/3	2
Attribute #3	2	3	1	5
Attribute #4	1/8	1/2	1/5	1

1

2

3.4583	7.5	2.0333	16

3

Attribute #1	0.2892	0.4000	0.2459	0.5000	0.359
Attribute #2	0.0964	0.1333	0.1639	0.1250	0.130
Attribute #3	0.5783	0.4000	0.4918	0.3125	0.446
Attribute #4	0.0361	0.0667	0.0984	0.0625	0.066

Final Score

4

A number greater than 1 indicates that you prefer the alternative in the row over the alternative in the column.

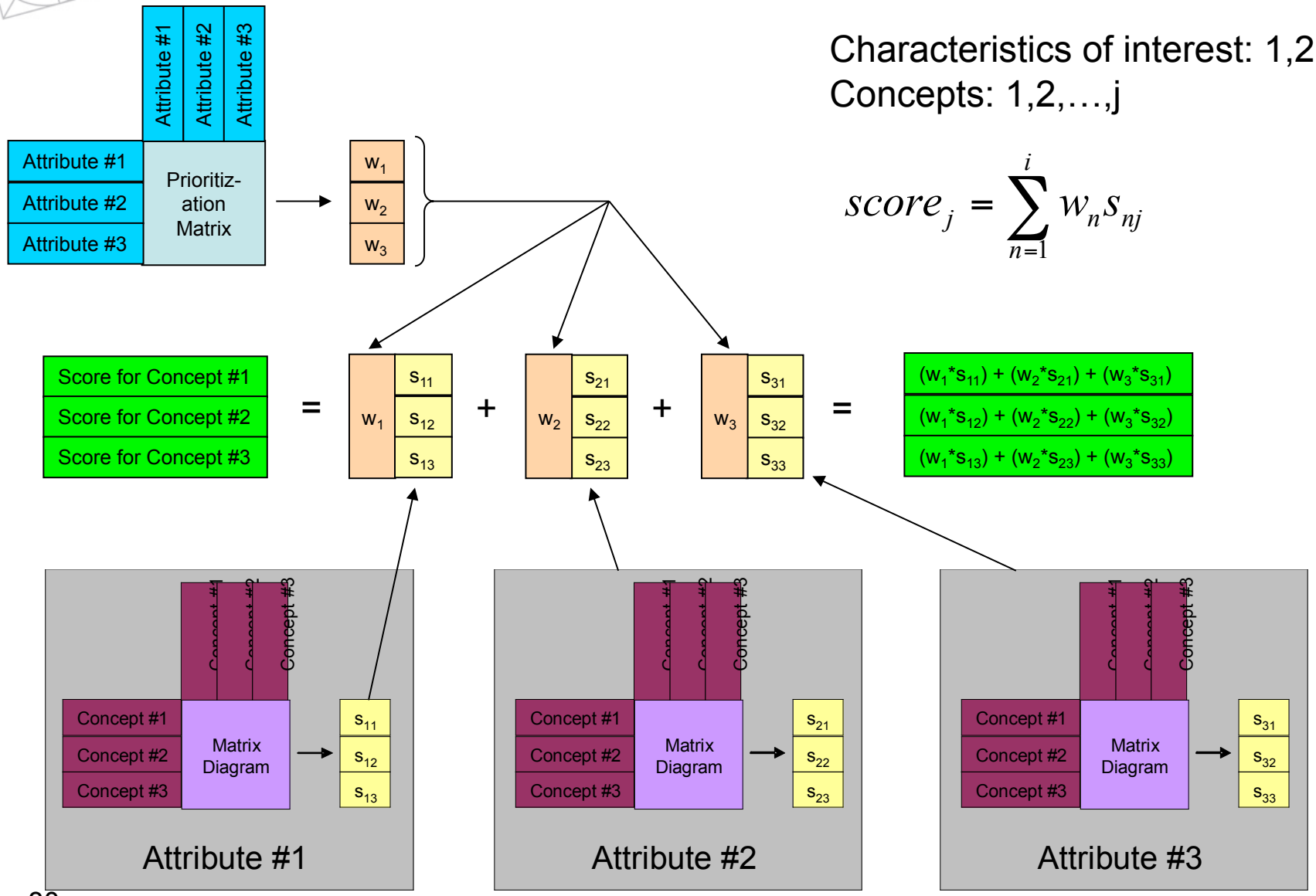
AHP Computational Procedure:

1. Populate AHP matrix by defining relative preferences on a1-9 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

9	Extremely Prefer
8	
7	Very Strongly Prefer
6	
5	Strongly Prefer
4	
3	Moderately Prefer
2	
1	Neutral

Using AHP to Rank Concepts



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-Scicon UK Limited, London

RESPONSE TO HOLDER'S COMMENTS ON THE ANALYTIC HIERARCHY PROCESS

RESPONSE TO THE RESPONSE

RESPONSE TO THE RESPONSE TO THE RESPONSE

* These articles appeared in *The Journal of the Operational Research Society* in 1990-1991

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

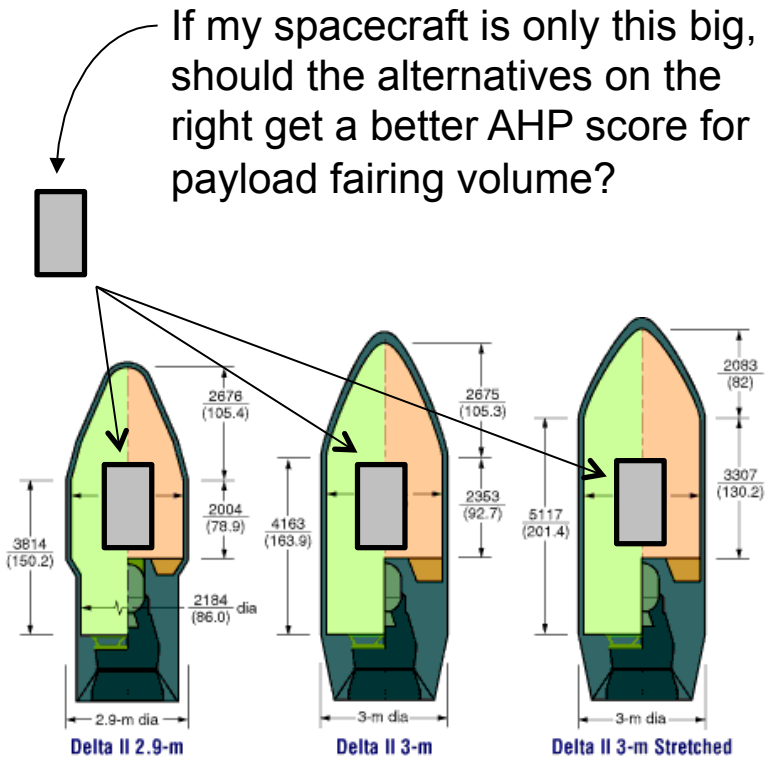
- AHP is a commonly used and widely accepted decision making tool
- AHP is uniquely equipped to compare quantitative and qualitative criteria in a common framework
- It only makes sense to compare options or alternative concepts that meet all the requirements (i.e. only consider feasible alternatives)
- 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.

In this scenario, should volume be a metric used in the AHP analysis?



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.

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*

Letter from Benjamin Franklin to Joseph Priestly in 1772, is taken from: "Letter to Joseph Priestly", Benjamin Franklin Sampler, (1956).

Module Summary: Analytical Hierarchy Process

- 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
  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.
- 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.