CHAPTER 12

TRADE STUDIES

12.1 MAKING CHOICES

Trade Studies are a formal decision making methodology used by integrated teams to make choices and resolve conflicts during the systems engineering process. Good trade study analyses demand the participation of the integrated team; otherwise, the solution reached may be based on unwarranted assumptions or may reflect the omission of important data.

Trade studies identify desirable and practical alternatives among requirements, technical objectives, design, program schedule, functional and performance requirements, and life-cycle costs are identified and conducted. Choices are then made using a defined set of criteria. Trade studies are defined, conducted, and documented at the various levels of the functional or physical architecture in enough detail to support decision making and lead to a balanced system solution. The level of detail of any trade study needs to be commensurate with cost, schedule, performance, and risk impacts.

Both formal and informal trade studies are conducted in any systems engineering activity. Formal trade studies tend to be those that will be used in formal decision forums, e.g., milestone decisions. These are typically well documented and become a part of the decision database normal to systems development. On the other hand, engineering choices at every level involve trade-offs and decisions that parallel the trade study process. Most of these less-formal studies are documented in summary detail only, but they are important in that they define the design as it evolves.

Systems Engineering Process and Trade Studies

Trade studies are required to support decisions throughout the systems engineering process. During requirements analysis, requirements are balanced against other requirements or constraints, including cost. Requirements analysis trade studies examine and analyze alternative performance and functional requirements to resolve conflicts and satisfy customer needs.

During functional analysis and allocation, functions are balanced with interface requirements, dictated equipment, functional partitioning, requirements flowdown, and configuration items designation considerations. Trade studies are conducted within and across functions to:

- Support functional analyses and allocation of performance requirements and design constraints,
- Define a preferred set of performance requirements satisfying identified functional interfaces,
- Determine performance requirements for lower-level functions when higher-level performance and functional requirements can not be readily resolved to the lower-level, and
- Evaluate alternative functional architectures.

During design synthesis, trade studies are used to evaluate alternative solutions to optimize cost, schedule, performance, and risk. Trade studies are conducted during synthesis to:

- Support decisions for new product and process developments versus non-developmental products and processes;
- Establish system, subsystem, and component configurations;
- Assist in selecting system concepts, designs, and solutions (including people, parts, and materials availability);
- Support materials selection and make-or-buy, process, rate, and location decisions;
- Examine proposed changes;
- Examine alternative technologies to satisfy functional or design requirements including alternatives for moderate- to high- risk technologies;
- Evaluate environmental and cost impacts of materials and processes;
- Evaluate alternative physical architectures to select preferred products and processes; and
- Select standard components, techniques, services, and facilities that reduce system life-cycle cost and meet system effectiveness requirements.

During early program phases, for example, during Concept Exploration and functional baseline development, trade studies are used to examine alternative system-level concepts and scenarios to help establish the system configuration. During later phases, trade studies are used to examine lower-level system segments, subsystems, and end items to assist in selecting component part designs. Performance, cost, safety, reliability, risk, and other effectiveness measures must be traded against each other and against physical characteristics.

12.2 TRADE STUDY BASICS

Trade studies (trade-off analyses) are processes that examine viable alternatives to determine which is preferred. It is important that there be criteria established that are acceptable to all members of the integrated team as a basis for a decision. In addition, there must be an agreed-upon approach to measuring alternatives against the criteria. If these principles are followed, the trade study should produce decisions that are rational, objective, and repeatable. Finally, trade study results must be such that they can be easily communicated to customers and decision makers. If the results of a trade study are too complex to communicate with ease, it is unlikely that the process will result in timely decisions.

Trade Study Process

As shown by Figure 12-1, the process of trade-off analysis consists of defining the problem, bounding the problem, establishing a trade-off methodology (to include the establishment of decision criteria), selecting alternative solutions, determining the key characteristics of each alternative, evaluating the alternatives, and choosing a solution:

- Defining the problem entails developing a problem statement including any constraints. Problem definition should be done with extreme care. *After all, if you don't have the right problem, you won't get the right answer.*
- Bounding and understanding the problem requires identification of system requirements that apply to the study.
- Conflicts between desired characteristics of the product or process being studied, and the limitations of available data. Available databases should be identified that can provide relevant, historical "actual" information to support evaluation decisions.
- Establishing the methodology includes choosing the mathematical method of comparison, developing and quantifying the criteria used for comparison, and determining weighting factors (if any). Use of appropriate models and methodology will dictate the rationality, objectivity, and repeatability of the study. Experience has shown that this step can be easily abused

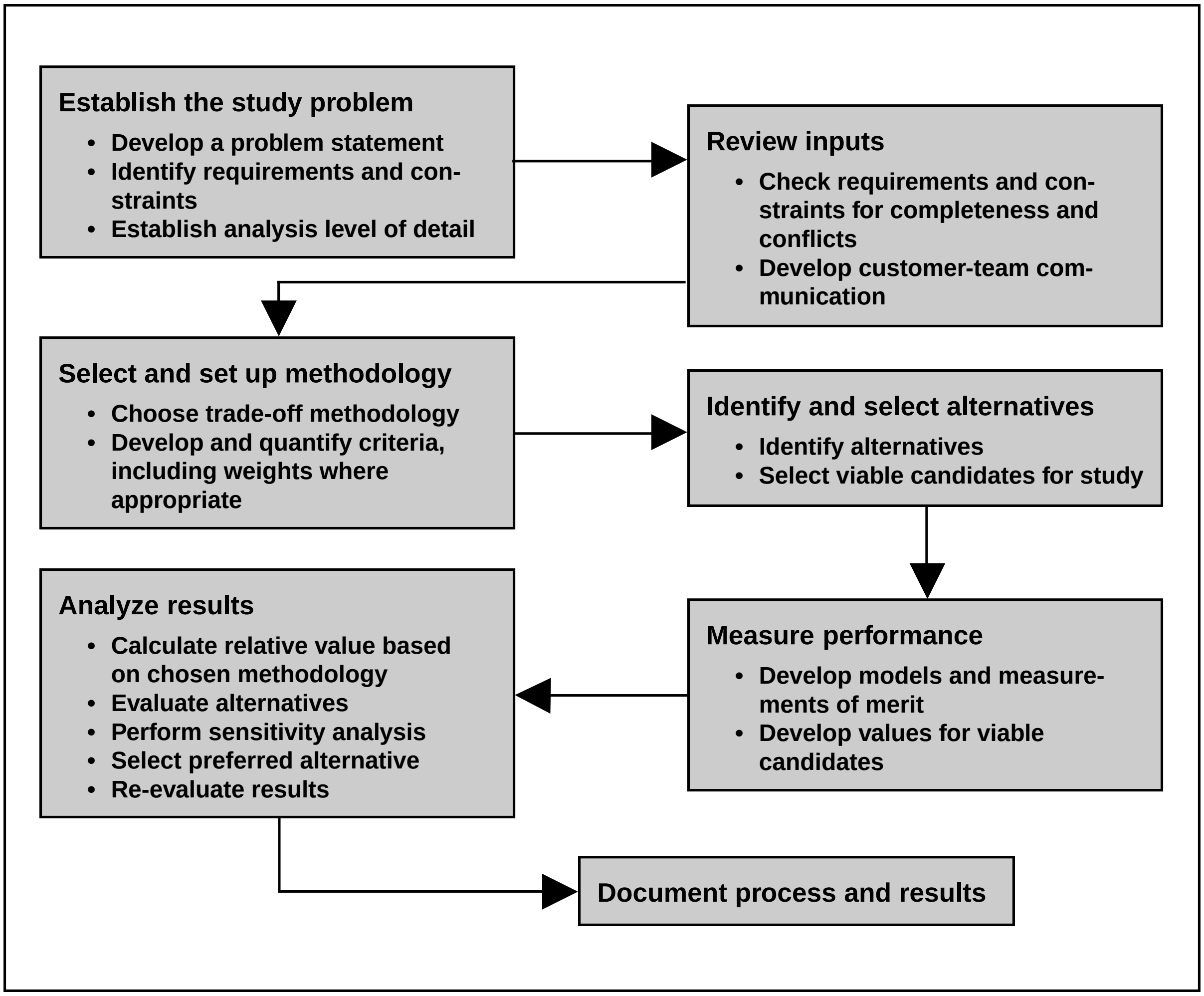

Figure 12-1. Trade Study Process

through both ignorance and design. To the extent possible the chosen methodology should compare alternatives based on true value to the customer and developer. Trade-off relationships should be relevant and rational. Choice of utility or weights should answer the question, "what is the actual value of the increased performance, based on what rationale?"

- Selecting alternative solutions requires identification of all the potential ways of solving the problem and selecting those that appear viable. The number of alternatives can drive the cost of analysis, so alternatives should normally be limited to clearly viable choices.

- Determining the key characteristics entails deriving the data required by the study methodology for each alternative.

- Evaluating the alternatives is the analysis part of the study. It includes the development of a trade-off matrix to compare the alternatives, performance of a sensitivity analysis, selection of a preferred alternative, and a re-evaluation (sanity check) of the alternatives and the study process. Since weighting factors and some "quantified" data can have arbitrary aspects, the sensitivity analysis is crucial. If the solution can be changed with relatively minor changes in data input, the study is probably invalid, and the methodology should be reviewed and revised. After the above tasks are complete, a solution is chosen, documented, and recorded in the database.

Cost Effectiveness Analyses

Cost effectiveness analyses are a special case trade study that compares system or component performance to its cost. These analyses help determine affordability and relative values of alternate solutions. Specifically, they are used to:

- Support identification of affordable, cost optimized mission and performance requirements,
- Support the allocation of performance to an optimum functional structure,
- Provide criteria for the selection of alternative solutions,
- Provide analytic confirmation that designs satisfy customer requirements within cost constraints, and
- Support product and process verification.

12.3 SUMMARY POINTS

- The purpose of trade studies is to make better and more informed decisions in selecting best alternative solutions.
- Initial trade studies focus on alternative system concepts and requirements. Later studies assist in selecting component part designs.
- Cost effectiveness analyses provide assessments of alternative solution performance relative to cost.

SUPPLEMENT 12-A

UTILITY CURVE METHODOLOGY

The utility curve is a common methodology used in DoD and industry to perform trade-off analysis. In DoD it is widely used for cost effectiveness analysis and proposal evaluation.

Utility Curve

The method uses a utility curve, Figure 12-2, for each of the decision factors to normalize them to ease comparison. This method establishes the relative value of the factor as it increases from the minimum value of the range. The curve shows can show a constant value relationship (straight line), increasing value (concave curve), decreasing value (convex curve), or a stepped value.

Decision Matrix

Each of the decision factors will also have relative value between them. These relative values are used to establish weighting factors for each decision factor. The weighting factors prioritize the decision factors and allow direct comparison between them. A decision matrix, similar to Figure 12-3, is generated to evaluate the relative value of the alternative solutions. In the case of Figure 12-3 range is given a weight of 2.0, speed a weight of 1.0, and payload a weight of 2.5. The utility values for each of the decision factors are multiplied by the appropriate weight. The weighted values for each alternative solution are added to obtain a total score for each solution. The solution with the highest score becomes the preferred solution. For the transport analysis of Figure 12-3 the apparent preferred solution is System 3.

Sensitivity

Figure 12-3 also illustrates a problem with the utility curve method. Both the utility curve and

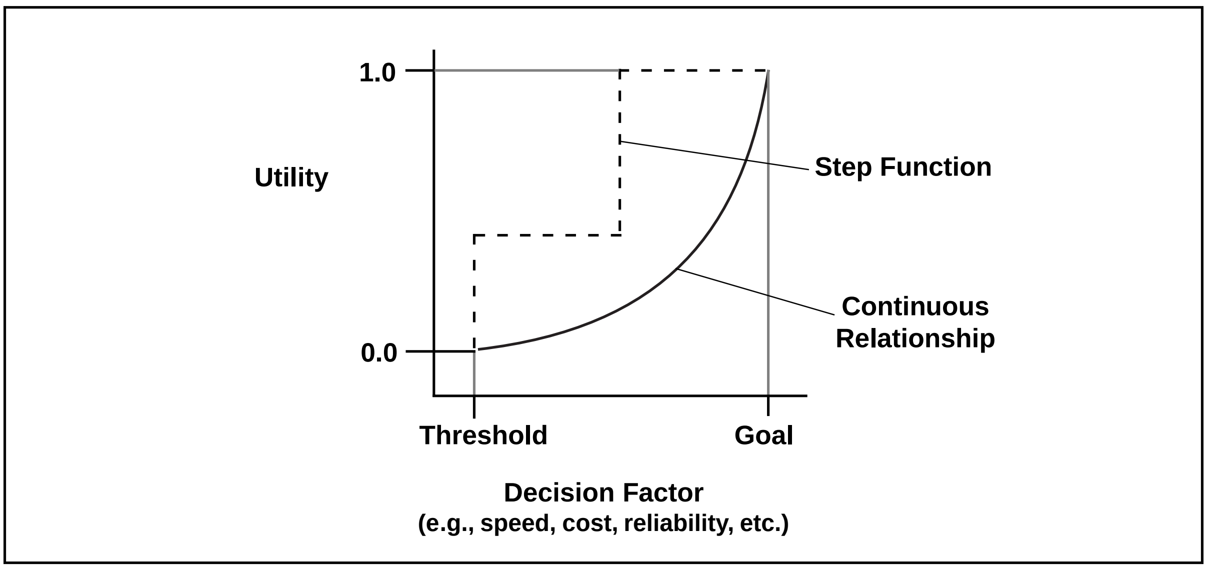

Figure 12-2. Utility Curve

weighting factors contain a degree of judgment that can vary between evaluators. Figure 12-3 shows three systems clustered around 3.8, indicating that a small variation in the utility curve or weighting factor could change the results. In the case of Figure 12-3, a sensitivity analysis should be performed to determine how solutions change as utility and weighting change. This will guide the evaluator in determining how to adjust evaluation criteria to eliminate the problem's sensitivity to small changes. In the case of Figure 12-3 the solution could be as simple as re-evaluating weighting factors to express better the true value to the customer. For example, if the value of range is considered to be less and payload worth more than originally stated, then System 4 may become a clear winner.

Notes

When developing or adjusting utility curves and weighting factors, communication with the customers and decision makers is essential. Most sensitivity problems are not as obvious as Figure 12-3. Sensitivity need not be apparent in the alternatives' total score. To ensure study viability, sensitivity analysis should always be done to examine the consequences of methodology choice. (Most decision support software provides a sensitivity analysis feature.)

Decision Factors / Alternatives	Range Wt. = 2.0		Speed Wt. = 1.0		Payload Wt. = 2.5		Weighted Total
	U	W	U	W	U	W	
Transport System 1	.8	1.6	.7	.7	.6	1.5	3.8
Transport System 2	.7	1.4	.9	.9	.4	1.0	3.3
Transport System 3	.6	1.2	.7	.7	.8	2.0	3.9
Transport System 4	.5	1.0	.5	.5	.9	2.25	3.75

Key: U = Utility value
W = Weighted value

Figure 12-3. Sample Decision Matrix