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## Change History

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<td>V 1.0</td>
<td>Initial TRA Release (Logan)</td>
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Executive Summary

This plan describes the overall approach and general framework for conducting trade studies for formal acquisition programs or Programs of Record (POR). The trade study approach is a four-phase effort to support major decisions to be made during the planning and execution of PORs. The phases are as follows:

- Initiate the Trade Study
- Develop the Summary Matrix
- Evaluate the Results
- Release Trade Study Report and Follow Course of Action

Whenever the cognizant Government decision-maker (referred to as the Decision Making Authority or DMA) determines a need for a specific trade study, the DMA appoints a Trade Study Lead to initiate the trade study and organize a Trade Study Team (TST).

The DMA conducts a series of gate reviews at selected points during the trade study to assess trade study progress and authorizes continuation, modification or termination of the effort as appropriate.

Depending upon the complexity of the trade space, the importance of the decision to be made and other programmatic factors, the trade study process may be tailored to suit the DMA’s needs.

Appendix A provides a detailed trade study plan checklist and template to track and document the progress of the trade study from initiation through completion.

Appendix B provides supplemental guidance on selected topics relevant to the trade study process.

Appendix C provides an overview of the six general features of the Preferred Approach to Trade Studies which are important elements of the approach described in this plan.

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1 This Trade Study Plan framework is adapted from material presented in the Defense Acquisition University (DAU) Continuous Learning Module entitled “The Preferred Approach to Trade Studies”, CLM 026, developed by Art Felix, formerly of the Naval Air Systems Command (NAVAIR) and presented to the International Council on Systems Engineering (INCOSE). It is highly recommended that prospective Trade Study Team Members browse or register for the CLM at https://learn.dau.mil.
1.0 Introduction to the Trade Study Plan

This document describes a four-phase approach to conducting trade studies:

- **Phase I – Initiate Trade Study:** In this phase, program management authorizes the start of the trade study. The Trade Study Lead drafts a program plan, assembles a team, establishes criteria and begins laying the groundwork for the trade study.

- **Phase II – Develop Trade Study Matrices:** The Trade Study Team analyzes various alternatives based on selected criteria. They organize the data they collect in trade study matrices.

- **Phase III – Evaluate Results:** In Phase III, the team evaluates results of the study. Cost and risk are introduced as factors. The team develops a recommended course of action.

- **Phase IV – Release Trade Study Report and Follow Course of Action:** In the final phase, the decision-maker implements the recommended course of action. The Trade Study Report, which documents the trade study, is written and published.

Although *four* phases are outlined in the full-fledged approach, the decision-maker can halt the trade study at any point. In addition, the phases are not necessarily discrete; there is some overlap among them. But the trade study approach does mandate that specific products or reviews must be completed before moving to the next phase.

The Chief Engineer, or a designated representative, will assign specific responsibilities to designated personnel for each trade study. The key personnel are:

- The Trade Study Lead (TSL) is responsible for the trade study. This responsibility includes initiating the trade study, assembling the trade study team, directing the collection of information, and making the final presentations to the DMA for approval and release.

- The Trade Study Team (TST) is responsible for supporting the TSL by gathering and developing data for the trade study as directed by the TSL. This information is required for the products and presentations to the DMA.

- The Decision-Making Authority (DMA) is responsible for making decisions on the trade study. These decisions are made at each of the mandated gate reviews. The DMA is often the Project Manager, the Product Director or the Chief Engineer who provides resources for the trade study and is dependent on the results for subsequent program execution.

Figure 1: Overview of the Trade Study Analysis depicts the steps taken during the conduct of a trade study as well as the products to be delivered in each phase. Trade study topics may result from previously identified trade study focus areas or unexpected technical issues that arise during the course of planning and executing a formal acquisition program or Program of Record (POR)
Figure 1: Overview of the Trade Study Process
2.0 Phase I: Initiate Trade Study

When the Program Management Office (PMO) identifies the need for a specific trade study, the PMO authorizes entry into Phase I of the trade study. The Trade Study Lead (TSL) drafts a detailed trade study plan, assembles a team and begins laying the groundwork for the trade study.

Specifically, Phase I includes the following steps:

- Develop a purpose/need statement and detailed trade study plan
- Conduct Gate 1 review
- Assemble the trade study team
- Generate alternatives
- Select tradable decision criteria
- Define baseline and ideal values
- Determine the criteria “weighting strategy”
- Conduct Gate 2(n) review

The focus of this phase is to establish how the trade study will be conducted and defines what data will be collected and how it will be analyzed.

2.1 Step 1: Develop Purpose/Need Statement and Trade Study Plan

2.1.1 Purpose/Need Statement

The purpose/need statement defines the scope of the trade study effort and serves as its overarching charter. Developed by the Trade Study Lead, the statement documents:

- The reason the study will be conducted
- The expected results and consequences of not doing the study
- The major program constraints that may impact the trade study

By documenting these constraints in the purpose/need statement ensures that the decision-maker is aware of them.

Constraints may come in the form of:

- Laws and regulations
- Political considerations
- Economic conditions
- Environmental impacts
- Safety considerations

2.1.2 Trade Study Plan

The Trade Study Lead also develops a trade study plan, which should include:

- Prospective team members (core and ad hoc)
- Objectives, scope and ground rules
- Tailoring the trade study process (if any)
• Resources required to complete the study
• Trade study schedule

In most cases, a trade study must be completed by a specific “need date”. This date will be mutually agreed upon by the TSL, the DMA and key stakeholders at the start of the effort.

The trade study schedule should take into consideration the possible need to repeat some activities. For example, to keep a program moving forward, the trade study team may be forced to select alternatives before sufficient data is available. This increases the risk of an incorrect decision. To mitigate this risk, alternatives should be reviewed again later, when data with a higher confidence level is available. The trade study plan should “build in” the potential need to repeat activities before a decision is finalized.

The trade study plan may be tailored based on the following:

• Life Cycle Phase. Early in the life cycle, data may be scarce and inexact. A less rigorous trade study could be conducted at that point, with greater rigor applied later when more detailed data becomes available.
• Criticality. For decisions that have little impact or risk, a less formal study will conserve resources for more critical decisions.
• Programmatic Considerations. If a tight deadline is looming, some trade study steps could be streamlined to provide support for decisions, while still adhering to time constraints.

2.2 Step 2: Conduct Gate 1 Review – Trade Study Go-Ahead

The DMA conducts a “gate review” in order to review the current status of the trade study and determine if it should continue. The goal of the first gate review is to ensure that the TSL and the DMA agree upon the following:

• The objective(s) of the trade study
• Its scope (what is and is not part of the trade study)
• Ground rules and assumptions
• Prospective team members
• Schedule
• Resources required to conduct the study

The Gate 1 review should be conducted as early as possible (ideally within a week after the trade study effort starts). Minutes and presentation materials will be maintained so they can be included in the Trade Study Report.

A successful gate review authorizes the trade study process to move forward.

2.3 Step 3: Assemble the Trade Study Team (TST)

The Trade Study Plan lists prospective trade study team members which the DMA will review and approve as part of the Gate 1 review.
In assembling the TST, it is critical that the TSL forms a cross-functional Integrated Product Team to ensure various perspectives are represented, and all issues relevant to the decision can be identified and considered.

Core team members usually serve on the team for the duration of the trade study. Additional ad hoc members may also be recruited to support special needs of the study.

The composition of each trade study team will vary, depending on the purpose of the trade study, its subject, life cycle phase and other factors. Representation may include:

- Program Management
- Systems Engineering
- Logistics
- Contracting
- Cost Analysis
- Test and Evaluation
- User organization(s)

2.4 Step 4: Generate Alternatives

Once the trade study team convenes, the first task is to generate alternatives. These might include the system in current use, several other existing systems or several variations of a new design. The generation of alternatives includes three activities:

- Brain-storming to identify a comprehensive set of alternatives to consider
- Identifying constraints that definitely disqualify certain alternatives (Go/No-Go constraints)
- Applying those constraints to identify 3-5 “viable alternatives”

2.4.1 A Comprehensive Set of Alternatives

In generating alternatives, the trade study team will first develop a comprehensive set of alternatives. This set is not confined to the practical alternatives. Rather, it includes all the possible alternatives that could provide a solution.

Many trade studies overlook the current solution as a possible alternative. (This is sometimes called the "no selection" or "do nothing" alternative.) This should be included in the comprehensive set, although it may be eliminated later.

Typically, the comprehensive set of alternatives is generated in a brainstorming session. Each alternative should be described in sufficient detail to capture its overall design concept.

Often decision-makers will question why a certain alternative was not considered. By generating a comprehensive set of alternatives—both practical and impractical, the team can counter that the alternative was considered but was removed from consideration for good reason.

2.4.2 Go/No-Go Constraints

Next, the team will disqualify some alternatives, coming up with a more manageable number by identifying Go/No-Go constraints.
Go/No-Go constraints relate to absolute “must-have” features, ones that must be addressed in the solution. If the alternative fulfills that requirement, the alternative is a Go — it can be considered for further study. If the requirement is not fulfilled, the alternative is a No-Go — it is disqualified from further consideration.

It is recommended that 3-5 viable alternatives advance for further study. Fewer than three alternatives may not provide sufficient variety for selection in the trade study. But going forward with more than five alternatives may be hard to manage, expensive and time-consuming. The current solution can be an alternative.

2.5 Step 5: Select Tradable Decision Criteria

After identifying the viable alternatives for further study, the team selects tradable decision criteria for the study. Decision criteria are the factors that will be used to evaluate alternatives. For example, alternatives may be evaluated based on criteria like performance.

In some cases, some of these criteria are “tradable”. An improvement in one criterion may result in a decline in another criterion. The team will conduct a brainstorming session to help generate a comprehensive initial list of possible criteria. In addition to identifying the criteria themselves, the team should clearly define each to avoid ambiguity later when alternatives are being analyzed.

Once the TST has generated the comprehensive initial list of possible criteria, this list should be narrowed down to 3-9 criteria. Fewer than three can bias the selection process; more than nine will overcomplicate the process and waste resources.

Another practical justification for limiting the number of tradable criteria: the percentage that the 10th, 11th, etc. criterion contributes to final solution is almost always 1% to 3%. This limited value does not justify the expense.

Two other important points about the tradable decision criteria are:

- Each criterion should be independent of the other criteria. Interrelationships among them make evaluation extremely complex. The team needs to ensure independence when selecting criteria.
- Cost and risk should not be selected as tradable criteria. Though often treated as tradable, when they are addressed in this way, their importance is diminished at the overall system level. Following the principles of the Preferred Approach to Trade Studies, the TST considers cost and risk later in the process, where their importance is optimized.

2.6 Step 6: Define Baseline and Ideal Values

For each decision criterion, the trade study team should define baseline and ideal values\(^2\).

Baseline values are associated with the existing design solution, the “as-is” condition and/or threshold values. Typically, these values are associated with the product that is being considered

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\(^2\) In some cases, the baseline value may be set by the Threshold \([T]\) specified in the capability document. Similarly, the ideal value may be set by the Objective \([O]\).
for replacement and represents the lower limit for each criterion. Ideal values are associated with a “want-to-be” condition, with a perfect solution that meets all needs, and/or objective values.

Example baseline and ideal values are provided in Table 1.

<table>
<thead>
<tr>
<th>Baseline Value</th>
<th>Ideal Value</th>
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<td>The Mean Time Between Failures (MTBF) for current system</td>
<td>The [Objective] MTBF specified in the Capability Development Document</td>
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Table 1. Example Baseline and Ideal Values

In cases where the baseline value cannot be established using the existing design solution, the team will look at an alternative that is as similar as possible and use the value for that alternative.

To provide a sound analysis, the team will be comparing alternatives based on selected decision criteria. However, comparing alternatives with diverse criteria can be much like comparing apples and oranges—with the same subjective results.

The baseline and ideal values provide the basis needed to empirically compare alternatives. These values “normalize” the various criteria, allowing a valid head-to-head comparison.

In Phase I, the team will define and plot baseline and ideal values on a graph called a utility curve. The team will develop a utility curve for each tradable criterion. The utility curve will establish the relative value of the criterion as it increases from the baseline value to the ideal value. The trade study team will use the relative value later to establish a “weight” for each criterion, thereby allowing it to be prioritized against other criteria.

The X-axis represents the value of that criterion; the Y-axis is a standard, normalized scale. For example, suppose one decision criterion used in a trade study is Mean Time Between Failures (MTBF). The utility curve format depicted in Figure 2 might be used.
In Phase I, the TST defines and plots the baseline and ideal values for each criterion on a utility curve.

### 2.7 Step 7: Determine the “Weighting Strategy”

The trade study team will use the baseline and ideal values to establish a *relative* value for each criterion. This will serve as the basis for assigning a weight and will allow for the prioritization of one criterion against the others.

However, before a specific weight is assigned, the team should determine the “weighting strategy” — whether to use a single-tier or a two-tier method of weighting.

- **A single tier method** considers each criterion individually in the comparison.
- **A two-tier method** groups the criteria into sub-groups. The individual criterion can be individually weighted within the sub-group; and the sub-groups can be weighted against each other.

### 2.8 Step 8: Conduct Gate 2(η) Review

The DMA will conduct a gate review in order to review the current status of the trade study and authorize moving forward. The goal of the second gate review is to present Phase I products to the DMA.

At the Gate 2 review, the decision-maker may:

- Approve the products and the continuation of the trade study
- Stop the trade study

*Figure 2: Example Utility curve – MTBF*
• Require reassessment of the Phase I products, requiring another review before proceeding to Phase II.

Due to the iterative nature of Phase I, there may be more than one gate review before proceeding to Phase II. The (n) is used to denote that there may be a first Gate 2(1) review, a second Gate 2(2) review, etc.

2.9 Phase I Products

• Purpose/need statement
• Program plan (schedule, resources)
• Trade study team
• Alternatives (comprehensive set winnowed down to the “viable alternatives”)
• Tradable decision criteria (along with definitions)
• Baseline and ideal values
• Weighting assignments
• Minutes from the Gate 1 review
3.0 PHASE II: DEVELOP TRADE STUDY MATRICES

In Phase II of the trade study, the TST begins the processes of data collection and alternative analysis. The TST organizes the results of this work into a series of trade study matrices for use in Phase III. Specifically, Phase II includes the following steps:

- Grade alternatives
- Score alternatives
- Compute weighting
- Determine “levels of uncertainty” for the criteria grades
- Compile costs for alternatives
- Assemble Summary Matrices

3.1 Step 1: Grade Alternatives

The trade study team begins their analysis using the alternatives and decision criteria previously identified and approved by the DMA. Each alternative is analyzed against the pre-defined decision criteria. For each alternative, the team establishes a grade for each of the decision criteria.

The grades usually come from actual data. If no actual data is available, the team will estimate the grade based on data for a similar alternative. The grade represents a “raw value” for each criterion.

In Phase I earlier, the team has taken care to reduce the number of alternatives and criteria that they will use going forward, being careful to provide clear definitions for the criteria. The reason for this care becomes apparent as the alternatives are graded.

- If a large number of alternatives and criteria are approved for further consideration, grading can become very time-consuming, expensive and challenging.
- As the TST assigns grades, the criteria often come under severe scrutiny. Questions about the definitions and scope of criteria may arise. For example, a criterion like “modularity” or “design simplicity” can be open to varying interpretations. A clear definition of the criterion facilitates grading and increases confidence in the grade.

3.2 Step 2: Score Alternatives

Once the grades are established, each grade is converted into a “score”. This is done using a utility curve, a graph that plots the raw grade for each criterion against a standard scoring scale as shown in figure 3.

- The X-axis of the utility curve represents the alternative’s grade for that criterion.
- The Y-axis consists of a standard scale against which the grade is plotted. Commonly used scales include 0-10, 0.0.1 (with increments in tenths) and 0%-100%.

Once the TST plots the grade, the utility curve establishes a relative, “normalized” value for each alternative’s grade. This allows the TST to prioritize the criteria in relation to one another and facilitates their comparison.
3.3 Step 3: Compute Weighting

At this point, the score reflects a “normalized” value for the criterion. The TST now applies an appropriate weight to each criterion. This generates a weighted score for each.

Earlier, the trade study team has determined the baseline and ideal values for each decision criterion, and plotted each on a utility curve. The utility curve establishes the relative value of the criterion as it increases from the baseline value to the ideal value. This relative value determines a weight for each criterion, thereby allowing it to be prioritized against the others.

Once a specific weight is determined, the team multiplies the standard score times the weight. This provides the weighted score for the criterion. For example: If a decision criterion has a score of 5.0 and is weighted at 2.0, then the weighted score is 10.0 (5.0 X 2.0 = 10.0).

Baseline values are associated with the existing design solution, the “as-is” condition. Typically, these values are associated with the product that is being considered for replacement and represents the lower limit for each criterion.

Ideal values are associated with a desired condition, with a perfect solution that meets all needs. In nearly all cases, this ideal solution does not exist, except theoretically.

3.4 Step 4: Determine “Levels of Uncertainty” for Criteria Grades

As the TST analyzes alternatives, they are responsible for determining a grade for each criterion, and also for determining the “level of uncertainty” of that grade. This level of uncertainty represents the team’s degree of confidence in the grade it has assigned.
The level of uncertainty is usually expressed as +/- a percentage, e.g., +/-10%, indicating the team’s belief that the grade may be 10% too low or 10% too high.

The team will determine uncertainty levels for each criterion. Each individual criterion will almost always have a different uncertainty level based on the characteristics of that criterion. In this way, the TST can better address uncertainty, increasing confidence in the trade study results.

3.5 Step 5: Compile Costs for Alternatives

After determining uncertainty levels, the TST will compile estimated costs for each alternative. These estimates are compiled using internal cost studies or historical data. For example, the team might identify all the components needed to build a particular alternative, research the cost of each component and compute a total. They would typically adjust this total based on the complexity of integrating the components (integration cost).

In addition to providing cost estimates for each alternative, the TST must also assess how much confidence they have in the cost estimate, i.e., the level of uncertainty in the alternative’s cost estimate. This level of uncertainty works very much like that used in assessing confidence in criterion grades.

The TST must clearly document and justify cost estimates for each alternative to show how the cost estimate was generated.

3.6 Step 6: Assemble Summary Matrices

The TST will compile and organize information collected in the analysis of the alternatives and organize it into Summary Matrices similar to that shown in Table 2. Each matrix lists each viable alternative under consideration and the decision criteria the TST used to analyze them. The summary matrices will present the following information:

- The score for each alternative/decision criteria
- Weight of the criterion and weighted score for each alternative/decision criteria
- Total weighted score for each alternative (the sum of all criteria scores for that alternative)
- Cost estimate for each alternative

The TST will assemble three related Summary Matrices:

- **Nominal**: One matrix indicates scores that do not factor in uncertainty levels for the criteria grades. These are sometimes called “nominal scores”.
- **Upper Limit**: A second matrix indicates scores that have been adjusted to the upper level of uncertainty. This is the + % for the uncertainty level (e.g., +30%). These upper levels are likely to be different for each criterion grade.
- **Lower Limit**: The third matrix indicates scores that have been adjusted to the lower level of uncertainty. This is the - % for the uncertainty level (e.g., -30%). These lower levels are likely to be different for each criterion.
3.7 Phase II Products

Phase II is considered complete when the TST has completed the following products:

- Grades and standardized scores for each alternative/decision criterion
- An uncertainty level for each criteria
- Weights and weighted scores
- A cost estimate for each alternative
- Summary Matrices presenting grades, standardized scores, weighted scores, total scores and costs for the alternatives. There should be matrices for the nominal values and ones adjusted for the upper and lower confidence levels for each criterion.

Each of these products should include clear documentation that outlines how it was generated.

There is no formal gate review at the end of Phase II, but completion of these products is necessary to signal the end of Phase II and the start of Phase III. The TSL will use a checklist (Refer to Appendix A) to ensure that each product has been completed.
4.0 Phase III: Evaluate Results

In Phase III of the trade study, the TST introduces the important considerations of cost and risk into the analysis. Traditional trade studies may consider cost and/or risk as tradable criteria, but there are significant drawbacks to doing this.

When cost and risk are used as tradable criteria, they are seen as characteristics of an alternative. Their importance at the system-level—as applied to the alternative as a whole—is lost. This is a serious problem in that the DMA’s interest is the cost and risk of the overall system.

In addition, cost and risk at the criteria level may have very narrow definitions. For example, risk may mean “the risk of not meeting some of the individual criteria grades”. This is very different than what risk should mean in a trade study—the risk of an alternative not succeeding in its application.

For these reasons, the Preferred Practices Approach does not treat cost and risk as tradable criteria. Instead, they're introduced in Phase III, where their importance is optimized.

4.1 Step 1: Generate Cost-Benefit Chart

The TST’s first step in Phase III is to generate a Cost-Benefit Chart similar to that shown in Figure 4. The Cost-Benefit Chart graphically shows the benefit of each alternative relative to its cost. The TST generates the chart by compiling the information from the Summary Matrices.

- The X-axis of the chart represents relative “benefit”, which is the final tabulated score for the alternative from the Summary Matrix.
- The Y-axis of the chart represents “cost”, which is the alternative’s cost as listed on Summary Matrix.

Each alternative is represented by a point on the chart where its benefit (total score) and cost intersect. The cost/benefit intersection points for all alternatives are plotted on the chart.

![Figure 4: Example Cost-Benefit Chart](image-url)
To help clarify alternatives in the yellow quadrant, the trade study team will need to:

- Set a baseline (lower limit) for benefit. The baseline value is established in Phase I of the trade study. As a rule of thumb, the TST sets the benefit baseline at 50%.
- Set cost limits. This is maximum allowable cost for an alternative and is determined by program management.

As Figure 4 illustrates, these limits help the TST and stakeholders see the alternatives more clearly. Some alternatives may now be below the benefits baseline; this means they don’t meet minimal performance standards. Other alternatives fall above the maximum allowable cost; this means they exceed cost limits.

In the previous series of Cost-Benefit Charts, the TST looked at each alternative as represented by a single intersection point of benefit score and cost. (This is sometimes called the nominal value). Next, the upper and lower levels of uncertainty for both scores and costs of each alternative should also be indicated on the Cost-Benefit Chart.

A second Cost-Benefit Chart as depicted in Figure 5 factors in the levels of uncertainty for both benefit and cost. Again, the "X" denotes the nominal benefit and cost values. The upper and lower values of uncertainty and cost are identified by the rectangle surrounding the "X". With these factored in, part of the Alternatives’ A and D rectangles now fall below the benefit baseline. This casts some doubt on the desirability of the alternative.

![Figure 5: Example Cost-Benefit Chart with Uncertainty Bounds](image)

If the alternative’s rectangle of uncertainty overlaps either the baseline or cost limit, the alternative should be closely scrutinized. The greater the overlap, the greater the scrutiny required by the TST.
4.2 Step 2: Conduct Risk Assessment

In addition to cost, a major consideration in the selection of alternatives is risk. In Step 2, the TST assesses risk levels for each alternative. The TST should document the reasons for assigning a specific risk level and include this documentation in the Trade Study Report.

After risk is assessed, the TST plots results of the risk assessment on a risk cube as shown in Figure 6. This graphs the severity (consequence) of the risk (on the X-axis) against the probability (likelihood) of its occurrence (on the Y-axis). As a result, the risk levels among the various alternatives become clearer.

Alternatives with a high probability of severe risk will fall into the “red zone”. Others will have low probability and low severity of risk, falling into the “green zone”. The remaining alternatives will range between high probability/low severity and low probability/high severity.

![Figure 6: Standard 5X5 Risk Cube](image)

4.3 Step 3: Generate Risk-Benefit Chart

Similar to the Cost-Benefit Chart, the Risk-Benefit Chart shows the benefit of each alternative relative to its risk by compiling information from the Summary Matrices and the Risk Cube.

- The X-axis of the Risk-Benefit Chart represents the “benefit” dimension, which is the alternative’s final score from its Summary Matrix.
- The Y-axis represents its relative risk. This is derived from the Risk Cube.

Each alternative is represented by a point on the chart where its benefit (total score) and risk intersect. The risk/benefit intersection points for all alternatives are plotted on the chart.
Figure 7: Alternative Comparison Risk/Benefit Chart

The Risk/Benefit chart clearly illustrates the benefit of each alternative with respect to its relative risk:

- The green rectangle contains low-risk alternatives.
- The yellow one indicates alternatives with moderate risk.
- The red rectangle contains high-risk alternatives.

4.4 Step 4: Conduct Risk Mitigation

The TST will not automatically eliminate riskier alternatives from further consideration. These alternatives may have tremendous benefit and risks can be mitigated. For each high-risk or moderate risk alternative, the TSL will generate a mitigation plan. (Low-risk alternatives don’t warrant risk mitigation plans.)

The risk mitigation plan outlines the risk(s) and indicates how the risk(s) will be addressed and managed. For example, risk might be mitigated by building a prototype or replacing some riskier components with more mature technologies.

In addition, the mitigation plan includes estimates of:

- The anticipated cost of implementing risk mitigation
- The expected risk reduction if the mitigation strategy is successful

4.5 Step 5: Develop Recommendation

At this point, the trade study team has collected and analyzed a great deal of useful information about the alternatives:

- Cost-benefit
- Risk-benefit
- Risk mitigation strategies; cost and benefits of implementing them
Based on these analyses, the TST will recommend an optimal solution.

4.6 Step 6: Generate Issues and Concerns

In the course of the trade study, the TST may uncover certain “issues or concerns” about the recommended alternative. These are based on unfavorable events that have happened in the past or that that may happen in the future. Issues and concerns are relatively minor, not serious enough to jeopardize the success of the alternative/project.

Though not as severe as “risks”, the TST should document these areas, bring them to the attention of the DMA and address them. If an issue or concern becomes more serious, it might need to be re-defined as a “risk”.

4.7 Conduct Gate 3(n) Review

The DMA will conduct another gate review in order to review progress on the trade study and authorize proceeding with the next steps. The goal of the third gate review is to provide Phase III summary data to the DMA. Products used in this presentation include:

- The Summary Matrices—one for the nominal data and additional ones to factor in upper and lower levels of uncertainty.
- Cost-Benefit and Risk-Benefit Charts
- The risk assessment, risk mitigation plan and issues/concerns
- The team's recommendation

The TST incorporates these products into the Trade Study Report, along with minutes for the Gate 3 review.

At the Gate 3 review, the DMA may:

- Approve the recommended alternative. This approval may be contingent on the closure of some minor action items, but this will not affect the outcome or next steps.
- Cancel or stop work on the trade study. This dramatic measure halts the trade study and is usually done for programmatic reasons, such as lack of resources.

However, there are times that the decision-maker may have serious concerns about the way the recommendation was formed. In these cases, he/she may decide that some of the analyses used in the trade study need to be repeated before a decision can be finalized.

The decision-maker may require the team to go back and re-assess:

- Alternatives or criteria
- Baseline/ideal value determinations for some or all criteria
- Grading, scoring or weighting of alternatives
- Determination of uncertainty levels
- Cost estimation for the alternatives
- Risk assessment for the alternative
• Require repeating some of the steps of the trade study. This would mean that another review would be required when those steps were completed. As a result, the \((n)\) is used to note additional Gate 3 reviews that might occur; for example, Gate 3(1) review, Gate 3(2) review, etc.

4.8 Phase III Products

• Artifacts presented at Gate Review
• Gate Review minutes
• Repeating of some analysis used in trade study as required by the DMA
5.0 Phase IV: Release Trade Study Report /Follow Course of Action

Phase IV begins when the DMA decides to continue with the trade study. A decision to continue may result from:

- Approval of the TST’s recommended alternative. In this case, the TST moves forward with the final steps of the trade study plan.
- A decision that some trade study steps need to be repeated before a sound decision can be made. In this case, the TST repeats the necessary activities and analyses before proceeding to the final steps.

Phase IV includes the following steps to conclude the trade study efforts:

- Finalizing the Trade Study Report
- Releasing the Trade Study Report

5.1 Step 1: Finalize the Trade Study Report

At the conclusion of the trade study, the TST will write and release a Trade Study Report. Concluding the trade study may be contingent on closing out minor action items, but this will not have a significant impact on the next steps.

The Trade Study Report summarizes the trade study and documents the processes and methods used to determine the recommended solution. The report is critical to:

- Documenting the “thinking process” underlying the decision-making
- Providing a record of the decision process
- Furnishing a valuable collection of information to others who might benefit from the documentation

In this step the TST is finalizing the report. Writing the Trade Study Report should be ongoing as the trade study is conducted. The TST should not wait until the trade study is completed, or valuable information will be forgotten and lost.

The TST should include all products developed during the trade study in the report. In addition, some summary elements (such as an Executive Summary and Lessons Learned) will need to be drafted for inclusion.

The final Trade Study Report should contain:

- Executive Summary
- Purpose/Need Statement
- Ground Rules and Assumptions
- Trade Study Constraints
- Program Plan (schedule, resources)
- Members of the trade study’s Integrated Product Team
• Trade Study Costs/Cost Savings
• Technical Summary (the actual products, such as alternatives, criteria, grading, charts, matrices, risk mitigation plans and other analyses)
• Recommendations
• Lessons Learned
• Appendices (information and minutes from the gate reviews as well back-up information)

5.2 Step 2: Release the Trade Study Report
After the DMA issues final approval of the Trade Study Report, the TSL releases the report to the Configuration Manager and other stakeholders as required.
Once released, the Configuration Manager is responsible for maintaining the report.

5.3 Phase IV Products
Phase IV is considered complete when the following have been accomplished:
• Minor action items are closed out
• The Trade Study Report is written
• The Trade Study Report is released to the Configuration Manager
APPENDIX A. DETAILED TRADE STUDY CHECKLIST AND PLAN TEMPLATE

The following checklist and report template can be used to track and document progress of a trade study through the four phases from initiation to completion.

<table>
<thead>
<tr>
<th>Trade Study Plan: &lt;Topic&gt;</th>
<th>&lt;date&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scheduled Start Date: &lt;date&gt;</td>
<td>Scheduled completion Date: &lt;date&gt;</td>
</tr>
<tr>
<td>Decision-Making Authority (DMA)</td>
<td></td>
</tr>
<tr>
<td>Trade Study Lead (TSL)</td>
<td></td>
</tr>
<tr>
<td>Trade Study Team:</td>
<td></td>
</tr>
<tr>
<td>&lt;functional area 1&gt;</td>
<td>&lt;name 1&gt;</td>
</tr>
<tr>
<td>&lt;functional area 2&gt;</td>
<td>&lt;name 2&gt;</td>
</tr>
<tr>
<td>&lt;functional area 3&gt;</td>
<td>&lt;name 3&gt;</td>
</tr>
<tr>
<td>&lt;functional area 4&gt;</td>
<td>&lt;name 4&gt;</td>
</tr>
<tr>
<td>Trade Study Purpose:</td>
<td>&lt;text here&gt;</td>
</tr>
</tbody>
</table>
# Phase I: Initiate Trade Study

<table>
<thead>
<tr>
<th>Tasks:</th>
<th>Date Approved:</th>
<th>Comments:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1: Purpose/Need Statement and Trade Study Plan</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2: Conduct Gate 1 Review</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3: Assemble Trade Study Team (TST)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 4: Generate Alternatives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 5: Select Tradable Decision Criteria</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 6: Define Baseline and Ideal Values</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 7: Determine “Weighting” Strategy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 8: Conduct Gate 2(n) Review</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Phase I Products Complete including</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gate 1 and Gate 2(n) Review Minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tasks:</td>
<td>Date Completed:</td>
<td>Comments:</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>-----------------</td>
<td>-----------</td>
</tr>
<tr>
<td>Step 1: Grade Alternatives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2: Score Alternatives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3: Compute Weights</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 4: Determine Levels of Uncertainty for Criteria Grades</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 5: Conduct Gate 3(n) Review</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 6: Compile Costs for Alternatives</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 7: Assemble Summary Matrices</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Phase II Products Complete</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Phase II: Develop Trade Study Matrices
# Phase III: Evaluate Results

<table>
<thead>
<tr>
<th>Tasks:</th>
<th>Date Completed:</th>
<th>Comments:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1: Generate Cost-Benefit Chart</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2: Conduct Risk Assessment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 3: Generate Risk-Benefit Chart</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 4: Conduct Risk Mitigation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 5: Develop Recommendation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 6: Generate Issues and Concerns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 7: Conduct Gate 3(n) Review</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All Phase III Products Complete including Gate 3(n) Review Minutes
<table>
<thead>
<tr>
<th>Tasks:</th>
<th>Date Completed:</th>
<th>Comments:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1: Finalize the Trade Study Report</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2: Release the Trade Study Report</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Trade Study Actions and Products Complete</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B. SUPPLEMENTAL TRADE STUDY GUIDANCE

1.0 Purpose
This appendix provides supplemental information that may be helpful to Trade Study Teams (TSTs) in planning and conducting trade studies. It is also useful to set management expectations for process improvement as the formal acquisition program is planned and executed.

2.0 The Value of Trade Studies

2.1 Trade Studies Provide a Record of the Decision-Making Process
A well-executed trade study will document the “thinking process” behind the decision. It will clearly outline how conclusions were drawn and how recommendations were formed. As a result, the decision-making process commands a high level of credibility, both immediately and later, in a record of events.

Very formal trade studies (e.g., those used in milestone decisions) are usually documented in detail. Less formal trade studies (e.g., basic engineering choices that occur at every level) are usually documented in summary. Even these summaries are important, however, in documenting the decision-making process.

2.2 Trade Studies Serve as a Valuable Collection of Information
Because well-executed trade studies are documented, they serve as valuable collections of data. This information can be an important resource in conducting future trade studies.

For this reason, it is important that the Trade Study Report be a complete record of the study and be written clearly. Any Systems Engineer should be able to read the report and follow it. This can improve results and save time, money and other resources in future trade studies.

2.3 Trade Studies Are Useful in a Broad Variety of Contexts
Trade Studies are used in support of decision-making throughout the acquisition life cycle of a program. From Concept Refinement to disposal, trade studies provide a critical decision tool. They can be applied in research, development, engineering, acquisition and sustainment of products.

Trade studies are routinely used to select among design architectures, to choose the preferred test approach and to support many formal program decisions. From systems-level decisions to the selection of lower-level alternatives, trade studies are commonly used as support mechanisms.

3.0 Building Better Trade Studies - Trade Study Success Factors
Trade studies are too often held responsible for the poor decisions made in an acquisition program. However, a closer examination of specific trade study processes reveals that it is the way trade studies are conducted in the “real world” that is often problematic. Such an examination yields some important lessons learned.

3.1 Four Keys to Effectiveness
A closer look at successful (and unsuccessful!) trade studies reveals important factors that can enhance effectiveness:

- Using a structured process
- Tailoring the trade study
- Documenting the process
- Updating the trade study

### 3.1.1 Use a Structured Process

Many organizations have an ill-defined process for conducting trade studies. There is little written direction and almost no training. Hence, much is left to the discretion of the individuals conducting the study.

In contrast, a structured process, such as the Preferred Practices Approach, provides standardization in:

- The steps and activities used to conduct the trade study
- Definitions of alternatives and criteria
- Grading, scoring, weighting
- Projections of benefit vice cost and risk, which factor in levels of uncertainty

The result is greater objectivity, credibility and confidence in the trade study’s recommendations.

### 3.1.2 Tailor the Trade Study

At times, trade studies are characterized as too imprecise; they lack the structure necessary to support sound decision-making. At other times, they are criticized for being too exacting, for taking too long and costing too much. But the real issue isn’t the trade study; it’s how it is tailored.

To enhance its effectiveness, a trade study should be customized to specific circumstances, like:

- Life Cycle Phase. For example, early in the life cycle, data may be scarce and inexact. A less rigorous trade study could be conducted at that point, with greater rigor applied later when more detailed data becomes available.
- Criticality. Why conduct a rigorous trade study for decisions that have little impact or risk? Instead, use a less formal study and conserve resources for more critical decisions.
- Programmatic Considerations. For instance, if a tight deadline is looming, some trade study steps could be streamlined. This would provide support for decisions, while still adhering to time constraints.

### 3.1.3 Document the Trade Study Process

Many trade studies are poorly documented. And in many cases, documentation efforts stop entirely as soon as a recommendation is approved; a Trade Study Report may not even be written.

- Clear documentation enhances the trade study, both now and for the future, by:
• Providing a record of the decision process
• Furnishing an important warehouse of information that could serve as valuable reference material for future efforts

3.1.4 Update the Trade Study

Many trade studies are conducted early on in an acquisition program when complete data may not be available. This can lead to:

• A premature selection of a solution. The trade study becomes, in essence, a defense of a pre-selected alternative as the “best option”.
• A selection based on only design-related criteria. The selection fails to consider long-term life cycle criteria, such as reliability and supportability.

These problems can be addressed by updating the study. When additional or more current information becomes available, alternatives should be reviewed again, and some trade study activities repeated. This iterative process leads to a much sounder “final decision”.

3.2 Level of Trade Study Formality: A Continuum

Another important trade study success factor relates to the level of formality in a trade study. Trade studies can be formal or informal. As a general rule, formal trade studies are indicated for high-value, high-risk or other high-impact decisions. But not all trade studies should follow the full rigor of a formal process. For decisions having a lower impact (in terms of cost or risk), an informal trade study is usually more appropriate.

The level of formality of a trade study should be tailored to specific circumstances, like those depicted in Figure 8. In this way, decisions can be effectively supported while still accommodating schedule, budget and other resource constraints.

<table>
<thead>
<tr>
<th>Informal</th>
<th>Intermediate</th>
<th>Formal</th>
</tr>
</thead>
<tbody>
<tr>
<td>• No programmatic impact/risk</td>
<td>• Programmatic impact/risk</td>
<td>• Programmatic impact/risk</td>
</tr>
<tr>
<td>• Lower-value decisions</td>
<td>• High-value decisions</td>
<td>• High-value decisions</td>
</tr>
<tr>
<td>• Fewer steps/activities</td>
<td>• More steps/activities</td>
<td>• More steps/activities</td>
</tr>
<tr>
<td>• Greater subjectivity</td>
<td>• Greater objectivity</td>
<td>• Greater objectivity</td>
</tr>
<tr>
<td>• Qualitative</td>
<td>• Quantitative</td>
<td>• Quantitative</td>
</tr>
<tr>
<td>• Less detailed documentation</td>
<td>• More detailed documentation</td>
<td>• More detailed documentation</td>
</tr>
<tr>
<td>• Less time, effort, cost of the trade study</td>
<td>• More time, effort and cost of the trade study</td>
<td>• More time, effort and cost of the trade study</td>
</tr>
</tbody>
</table>

Figure 8: Level of Trade Study Formality
4.0 Trade Study Metrics

Trade studies — formal trade studies in particular — represent a significant investment in program resources. As a result, there’s a reasonable expectation that they add value to a program. To objectively measure the value added, process metrics are used. Trade Study metrics have two related roles: monitoring and process improvement.

4.1 Monitoring and Process Improvement Metrics

Initially, process metrics measure how well a program is going. For example, let’s say you’re using the number of calendar days as a metric. The program plan indicates that Phase I should take three weeks, but the phase is completed in only two weeks. By monitoring the number of days, we can see that the program is going well.

Over time, metrics also provide a basis for process improvements. This time, let’s say that the program plan allows four weeks for Phase II, but the team is well into the sixth week, with no end in sight. They begin to look at other metrics to find the cause for this. They find that they have identified twelve “viable alternatives”; analyzing all twelve is taking far more time than they allotted. Process metrics help the team identify a problem… and a process improvement opportunity.

Examples of metrics that may be used for monitoring and process improvement include:

- Planned vs. actual duration of each phase (calendar time)
- Total number of alternatives considered; number of viable alternatives selected
- Number of tradable criteria to be analyzed
- Uncertainty level of each criterion, in terms of benefit and cost
- Cost and risk of each viable alternative
- Cost of risk mitigation; change in potential risk after implementation of risk mitigation
- Number of Gate 1(n), 2(n), and 3(n) reviews
- Number of updates to the trade study one year later
- Cost of the solution as estimated in the trade study vice actual cost

Before the trade study begins, the Program Manager should establish the specific trade study metrics that will be employed.

4.2 Metrics and the Preferred Practices Approach

The Preferred Practices Approach facilitates the gathering of metrics used for process improvement.

- It employs a deliberate, step-by-step approach; data is systematically collected throughout the process. This data can easily be used to monitor and improve processes.
• In addition, in the Preferred Practices Approach, data and processes are documented. As a result, data that can be used for measurement and improvement is readily available.

5.0 Weighting Strategies

Using a single-tier method, each of the criteria is individually included in a comparison. Using a two-tier method, the team groups some of these criteria into sub-groupings.

In the two-tier method, the sub-groups can be assigned different weights and be weighed against each other. For example, the TST might decide that on criteria more important than another. In addition, the individual criteria within sub-groups can be individually weighted within that sub-group. In this way, criteria of varying priorities can be more easily compared.

6.0 Addressing Levels of Uncertainty

The level of uncertainty represents the TST’s lack of confidence in the grade it has assigned. It is usually expressed as +/- a percentage, e.g., +/-10%. This indicates the TST’s conviction that the grade may be 10% too low or 10% too high.

The level of uncertainty for a primary decision criterion may be associated with maturity of the alternative. For example, Table 3 shows how a TST may assign uncertainty levels:

<table>
<thead>
<tr>
<th>Level of Maturity</th>
<th>Uncertainty Level</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>The alternative has never been built or even prototyped. No direct data on the alternative</td>
<td>May be as high as +/- 50%</td>
<td>The team is not very confident about the grade assigned.</td>
</tr>
<tr>
<td>A functional operational prototype exists for the alternative (brass board, breadboard or equivalent)</td>
<td>Although there is only limited data about the alternative, the uncertainty level may decrease to +/- 30%.</td>
<td>Increasing level of confidence</td>
</tr>
<tr>
<td>A functional engineering model exists for this alternative</td>
<td>Availability of more data decreases the uncertainty level to +/- 20%.</td>
<td></td>
</tr>
<tr>
<td>A production model of the alternative exists</td>
<td>With the availability of operational data related to the alternative, the uncertainty level is reduced to +/-10%.</td>
<td>The team is more confident about the grade assigned.</td>
</tr>
</tbody>
</table>

Table 3. General Guidelines for Assigning Levels of Uncertainty

Likewise, the level of cost uncertainty can be a factor of supplier maturity as well, as in Table 4.
<table>
<thead>
<tr>
<th>If the supplier has:</th>
<th>The cost uncertainty level might be set at:</th>
<th>Rationale:</th>
</tr>
</thead>
<tbody>
<tr>
<td>No experience in this field</td>
<td>+/- 50%</td>
<td>The cost risk is high</td>
</tr>
<tr>
<td>Experience in this field, but has never put a functional prototype in operation</td>
<td>+/- 40%</td>
<td>There is less risk, but the supplier is not exactly a proven commodity</td>
</tr>
<tr>
<td>Experience in this field and has developed functionally close units</td>
<td>+/- 30%</td>
<td></td>
</tr>
<tr>
<td>Functional units delivered and in operation; these are nearly the same as the alternative under consideration</td>
<td>+/- 20%</td>
<td>Confidence in the supplier and the costing increases</td>
</tr>
<tr>
<td>Delivered the exact form, fit and function as the alternative under consideration</td>
<td>+/- 10%</td>
<td>Cost uncertainty is low</td>
</tr>
</tbody>
</table>

Table 4. General Guidelines for Assigning Levels of Cost Uncertainty

7.0 Role of Trade Studies in Establishing Technical Baselines and Conducting Technical Reviews

Trade studies may be conducted prior to the System Functional Review (SFR) to:

- Ensure that the approved Functional Baseline is executable within the existing budget and schedule
- Evaluate alternative functional architectures to select the one that decomposes the system performance in the best possible way (consistent with the mature system concept and known risks)

Trade studies may also be conducted prior to the Preliminary Design Review (PDR) to:

- Compare alternative designs (physical architectures) for each configuration item or subsystem within the system to develop the best Allocated Baseline
- Ensure that the subsystem requirements correctly and completely implement all system requirements allocated to the subsystem at the time of the review
8.0 Decision Support Tools Used in Trade Studies

Trade studies employ a structured decision-making process. An important part of this is the application of empirical “decision support tools”. Decision support tools commonly employed in trade studies include:

- Utility Curves
- Delphi Method
- Decision Trees
- Analytical Hierarchy Process (AHP)
- Quality Function Deployment (QFD)
- Pugh Controlled Convergence

A single trade study can use more than one of these decision-support tools. In fact, that is recommended. Because the decision support tools are mutually supportive, it is advantageous to use them in combination. The greater the number of tools used, the better the decision that results.

8.1 Utility Curve

A utility curve is a graph that can be used to compare decision criteria. A utility curve is developed for each criterion (for example, speed, reliability or fuel consumption). The utility curve plots the relative value of the criterion as it increases from the minimum allowable value (for example, 1) to the best possible value (for example, 10). In this way, the utility curve “normalizes” the various criteria and allows them to be prioritized in relation to one another.

Utility curves are also used to compare the desirability/benefit of alternatives relative to one another. The curve plots the grade for each alternative against a standard scoring scale (such as 0-1.0). Again, this normalizes the grades, allowing for a more standardized comparison of alternatives.

8.2 Delphi Method:

The Delphi Method is a decision support tool that uses expert opinion and consensus.

- The trade study team identifies a group of experts (usually referred to as the “respondent group”).
- The team captures the opinions of these experts in an iterative fashion until a consensus is reached.

8.3 Decision Trees

Decision trees graphically depict various decisions and the consequences of each. These consequences may include outcomes, payoff and cost of each decision.

Decision trees are used when a large number of options exist. These facilitate selecting an option with the greatest expected value or least expected cost. In a trade study, these “options” might be alternatives.
Decision trees assign a probability to each option and estimate its payoff (or cost). Multiplying the pay off (or cost) by the probability provides a projected value (or cost) for each option. The team can then select the option with the highest expected value (or the least expected cost).

### 8.4 Analytical Hierarchy Process (AHP):

The Analytical Hierarchy Process (AHP), developed by Thomas Saaty of the University of Pittsburgh, focuses on “weights” in order to select the most favorable alternative. AHP assigns weights to criteria and other alternative decisions; the option with the highest weight is considered to be the best option.

AHP is based on the idea that a complex decision can be effectively examined if it is decomposed into its parts. It establishes a hierarchy of objectives, criteria and alternatives. Elements at a given level are compared only to other elements on that level. A pair-wise comparison, using the scale in Figure 9 below, assesses each pair with respect to their effect on elements at the higher level. The pair-wise comparisons are then manipulated mathematically to determine the weight of each criterion and the overall weight for each alternative.

![Figure 9: Scale for AHP Pair-wise Comparisons](image)

### 8.5 Quality Function Deployment (QFD):

Quality Function Deployment (QFD), developed by S. Mizuno and Y. Akao, is an effective tool for identifying the critical characteristics of a system from various perspectives — the customer, engineers, developers, etc.

A graphic tool called the House of Quality (refer to Figure 10) is used to assess whether improving one requirement causes: (1) a deterioration, or (2) an improvement in other technical requirements under consideration. If the result is a deterioration, a trade-off exists.
8.6 Pugh Controlled Convergence:

Pugh Controlled Convergence, developed by Stuart Pugh, looks at each criterion for an alternative and judges it as better or worse than an established baseline. This type of study requires:

- Baseline value, which indicates the minimum allowable value for the criterion (reliability or speed, e.g.)
- Ideal value, which indicates a “perfect” standard solution against which the alternatives are to be compared

Each criterion is assessed against the baseline value — it is better than the baseline or worse. For example, the reliability of Alternative A is better than the baseline value; the reliability of Alternative B is worse. The alternative with the most “better than” assessments is selected.

Although a strict version of Pugh Controlled Convergence implies that each criterion has equal importance, criteria can be weighted in a modified version of this trade study type.

9.0 Types of Trade Studies

There are six basic types of trade studies. These types differ in terms of:

- How the decision is made (how the criteria are assessed)
- The level of information (detail) that is required as input
- The time and resources needed to conduct the study
The six types of Trade Studies are:

- Single Criterion Selection
- Pros/Cons Trade-Off Study
- Multiple Criteria Selection
- Relative Comparison (Basic)
- Relative Comparison (Advanced)
- Complete Trade Study

9.1 Single Criterion Selection

The Single Criterion Selection is used when only one criterion is used to make the decision. For example, the single criterion used to make the decision might be reliability. In this case, the solution would be based on which alternative is most reliable.

In the Single Criterion Selection, it’s important to document the definition of the criterion and the rationale behind the selection of a particular alternative. Otherwise, in retrospect, the decision process may be seen as skewed.

The Single Criterion Selection does not require a high level of detail in the data used as input. It also tends to require less time and fewer resources than other trade study types.

9.2 Pros/Cons Trade-Off Study

The Pros/Cons Trade-Off Study judges each alternative by listing its Pros/Cons. Pros/Cons for each alternative can be based on the same set of criteria; for example, Alternatives A, B and C are all judged on Mean Time Between Failures (MTBF), fuel consumption and ease of servicing. Or Pros and Cons for the alternatives can be based on different criteria. Alternative A has excellent fuel consumption; Alternative B has a high MTBF.

The composite of the Pros/Cons for a particular alternative are rolled into a single numerical value, then the alternative is assigned a relative benefit value. In the end, the Pros/Cons Trade-Off Study can indicate the position of alternatives based on their benefit, without requiring detailed data as input.

9.3 Multiple Criteria Selection

The Multiple Criteria Selection trade study is used when multiple criteria are used to decide among alternatives. For example, the selection might be based on reliability, speed and environmental impact. In this case, the alternative with the best possible mix of these three criteria would need to be identified.

To do this, the trade study employs a scale to judge the relative benefit of each criterion. These criteria benefits are rolled into a single figure that represents the composite benefit for the alternative. This kind of assessment requires some quantitative knowledge of the value of the criteria. Generally, it also requires more time and resources than the Single Criterion or Pros/Cons studies.

9.4 Relative Comparison (Basic)

In a Relative Comparison (Basic) study, each criterion for an alternative is assessed relative to a baseline (minimum allowable) value. With respect to that value, the criterion is given a relative
ranking. For example, the reliability of Alternative A is better than the baseline; the reliability of Alternative B is much better. Obviously, this requires some detail in the data used as input.

In the Relative Comparison (Basic) study, a textual description outlines the relative differences in criteria and provides a rationale for the ranking. It is important to note, however, that specific numerical values are not determined or documented.

9.5 Relative Comparison (Advanced)

The Relative Comparison (Advanced) study builds on the Basic. Again, each criterion for an alternative is assessed relative to a baseline (minimum allowable) value. But its relative ranking is numerical. Instead of being “much better” than the baseline value, a criterion may be assigned a value of 0.6. This suggests a relatively high level of detail in the data used as input.

The Relative Comparison (Advanced) study assigns weights to the criteria; these indicate the relative importance of each criterion. To assign these weights, a utility curve is used. This plots a grade for a criterion against a standard scoring system, normalizing the criteria and facilitating comparison.

In the Relative Comparison (Basic) study, a textual description outlines the relative differences in criteria and provides a rationale for the relative ranking. In the Relative Comparison (Advanced) study, the textual description is supplemented with numerical values.

9.6 Complete Trade Study

The Complete Trade Study is a full-fledged trade study that utilizes very detailed input and generates very detailed products and documentation. It is the most rigorous of all the trade study types.

The Complete Trade Study features some activities not performed in other types:

- From a comprehensive set of alternatives, it selects a “viable alternatives” subset.
- It applies a “level of uncertainty” to the benefit ranking of each criterion. This indicates the team’s lack of confidence in the ranking. It is expressed as +/- a percentage; this indicates that the actual value could work out to be that much higher or lower than the assigned ranking.

While the Complete Trade Study provides a high level of objectivity, it also requires the most time, effort and money.
APPENDIX C. SIX GENERAL FEATURES OF THE PREFERRED APPROACH TO TRADE STUDIES

The Preferred Practices Approach incorporates six important features that distinguish it from traditional trade studies processes:

1. **Definition of a Framework and Structure**
   The Preferred Practices Approach outlines a framework and structure that includes four phases and their associated work products, roles and responsibilities.

2. **Removal of Cost and Risk as Decision Criteria**
   In traditional trade studies, cost and risk are treated as individual decision criteria; this diminishes their importance at the system level. In the Preferred Approach, cost and risk are considered later in the process.

3. **Analysis of Cost/Benefit**
   After alternatives have been analyzed against the decision criteria, cost is introduced. The cost of each alternative is charted against its benefit. This provides the decision-maker with a clearer picture of relative benefits and cost at the system level.

4. **Analysis of Risk/Benefit**
   Risk is treated similarly to cost. Once the alternatives have been analyzed using the other criteria, risk is assessed. The risk of each alternative is charted against its benefit, providing a clearer picture of relative benefits and risks at the system level.

5. **Definition of Baseline/Ideal Values**
   For each decision criterion, baseline and ideal values are defined. Baseline values are usually associated with the existing design solution (e.g., speed of the aircraft in use now). Ideal values represent the best possible solution, one that perfectly meets all needs. These values provide the basis needed to empirically analyze trade-offs among alternatives.

6. **Definition of Levels of Uncertainty for Each Criterion**
   During the trade study, evaluators assign “grades” for decision criteria. In addition, they assign “levels of uncertainty”; this represents their lack of confidence in the grade they have assigned.
   
   In traditional trade studies, a uniform level of uncertainty is applied. But, in the Preferred Approach, a level of uncertainty is assessed for each criterion. In this way, uncertainty can be better addressed, increasing confidence in the results of the study.
APPENDIX D. LIST OF ACRONYMS

The following acronyms have been used in this document.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHP</td>
<td>Analytical Hierarchy Process</td>
</tr>
<tr>
<td>CLM</td>
<td>Continuous Learning Module</td>
</tr>
<tr>
<td>DAU</td>
<td>Defense Acquisition University</td>
</tr>
<tr>
<td>DMA</td>
<td>Decision Making authority</td>
</tr>
<tr>
<td>DoD</td>
<td>Department of Defense</td>
</tr>
<tr>
<td>INCOSE</td>
<td>International Council on Systems Engineering</td>
</tr>
<tr>
<td>MTBF</td>
<td>Mean Time Between Failures</td>
</tr>
<tr>
<td>NAVAIR</td>
<td>Naval Air Systems Command</td>
</tr>
<tr>
<td>PDR</td>
<td>Preliminary Design Review</td>
</tr>
<tr>
<td>PM</td>
<td>Program Manager</td>
</tr>
<tr>
<td>PMO</td>
<td>Program Management Office</td>
</tr>
<tr>
<td>POR</td>
<td>Programs of Record</td>
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<tr>
<td>QFD</td>
<td>Quality Function Deployment</td>
</tr>
<tr>
<td>SFR</td>
<td>System Functional Review</td>
</tr>
<tr>
<td>TSL</td>
<td>Trade Study Lead</td>
</tr>
<tr>
<td>TST</td>
<td>Trade Study Team</td>
</tr>
</tbody>
</table>