COTS SELECTION CRITERIA
IN
GOVERNMENT PROGRAMS

By

Eric Reintjes

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APPROVED:

Benjamin S. Blanchard, Chairman

Wolter J. Fabrycky

Frank E. Mintz

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Eric E. Reintjes

Committee Chairman: Benjamin S. Blanchard

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(ABSTRACT)

The process involving the design and acquisition of systems for the Government sector has recently shifted its emphasis from mostly custom designed equipment to the extensive use of Commercial-Off-The-Shelf (COTS) hardware and software. Because the relative merits of custom or COTS are not clearly understood by the design engineers, the correct parameters and criteria are not always properly identified.

This study investigated the decision criteria for the selection of COTS vice custom designed systems, assemblies and components in the design phases of the system life-cycle. Since Government requirements differ from those of commercial customers, selection was considered from the perspective of the Government customer. The operational conditions pertinent to the Government environment were used to determine the relevant criteria in the selection of the system components. The parameters selected and evaluated were life-cycle cost, effectiveness, unit data, system support and supplier rating. Sub-categories included items such as standardized fit, existing field population, established design, reliability, source of reliability data, software interfaces, and cost. Other considerations such as maturity of technology and rate of technological change were also discussed. A definition or description of each selection criterion, as well as the validity of that measure were examined. Trade-offs and weighting factors to select the best solution were also recommended.

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Introduction

Recent changes to the Federal Acquisition Regulation (FAR) promote the acquisition of commercial items for use in Government programs. These changes, according to Bob Dornan, senior vice president of Federal Sources Inc., will require "...market research to determine if requirement(s) can be satisfied with commercial items, thus promoting greater communications between vendors and the Government."[1] The problem is to determine the parameters needed to perform an objective evaluation of the commercial items available, and weigh the advantages of traditionally designed custom equipment against these "Commercial Off-The-Shelf" (COTS) solutions.

This study provides the basis for the use of certain criteria required in the evaluation of both commercial and custom designed alternatives at the design phases of the system life-cycle. A checklist will be developed, providing an index of data requirements that must be amassed prior to the decision and selection process. A decision methodology utilizing a weighting criterion for the evaluation of the various data and for the objective selection of a solution will also be presented.

To provide a decision methodology and arrive at the checklist, this study examines the present evolution toward the use of COTS-based systems in Government programs, and the reasons behind this shift. Then, in order to provide a common basis for discussion, certain terms are defined. The various points in the system engineering process that are decision points in the COTS/custom selection process are discussed, followed by an examination of the advantages and disadvantages of COTS equipment and products. Other evaluation criteria that must be considered in the decision process are also

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[1] Robert Dornan, "Dornan on Rules & Regs," *Federal Computer Week*, 9 (20 March 1995), 15.

examined, and the data required to make a decision is discussed. Finally, a checklist and the associated weighting criteria guidelines are derived.

The selection of commercial off-the-shelf (COTS) products as a solution to system performance requirements in United States Government programs has a profound impact on a system's production, operational use, and system support phases. The decision to use COTS or custom products occurs at the conceptual design and advanced planning phases of the system life-cycle, as well as at the detail design phase. At all of these phases, the decisions and the selection of the proposed solutions are performed by design engineers, planners and program managers who may not fully comprehend the impact their decision will have on the production, operations and maintenance phases of the system life-cycle. The design engineer, supported by the program manager and planners, must weigh all of the advantages and disadvantages of using a COTS solution versus a custom design to arrive at the best solution for the given data, understood customer needs, and system requirements. A decision methodology and accompanying checklist intended to assist the design engineer have been developed by examining the factors that have a bearing on this decision.

Background

In an effort to reduce program costs, the Government has shifted the procurement of systems, whenever possible, from custom equipment with mostly original equipment manufacturer (OEM) maintenance, to systems composed of commercial off-the-shelf (COTS) components with either OEM or third party maintenance. Reduced operational and maintenance costs of COTS equipment have been cited in some applications as the sole reasons to replace existing equipment, even in situations where the equipment capabilities are not significantly enhanced.

System developmental time constraints and costs are also major factors in the shift toward COTS products. It is estimated that, because of the direct relationship between developmental time and program costs, the savings realized through the purchase of already developed items is at least 75%[2]. Today, Government requests for new systems also allow considerably less time between the Request for Information (RFI) or Request for Proposal (RFP) and the delivery date than has been allowed in the past. This type of time constraint forces contractors to search for ready-made solutions to performance requirements. COTS products, by definition, are existing solutions that can be applied to any such problem. As a result, the time needed to secure commercial solutions is considerably less than the time required to develop custom products which would support system requirements.

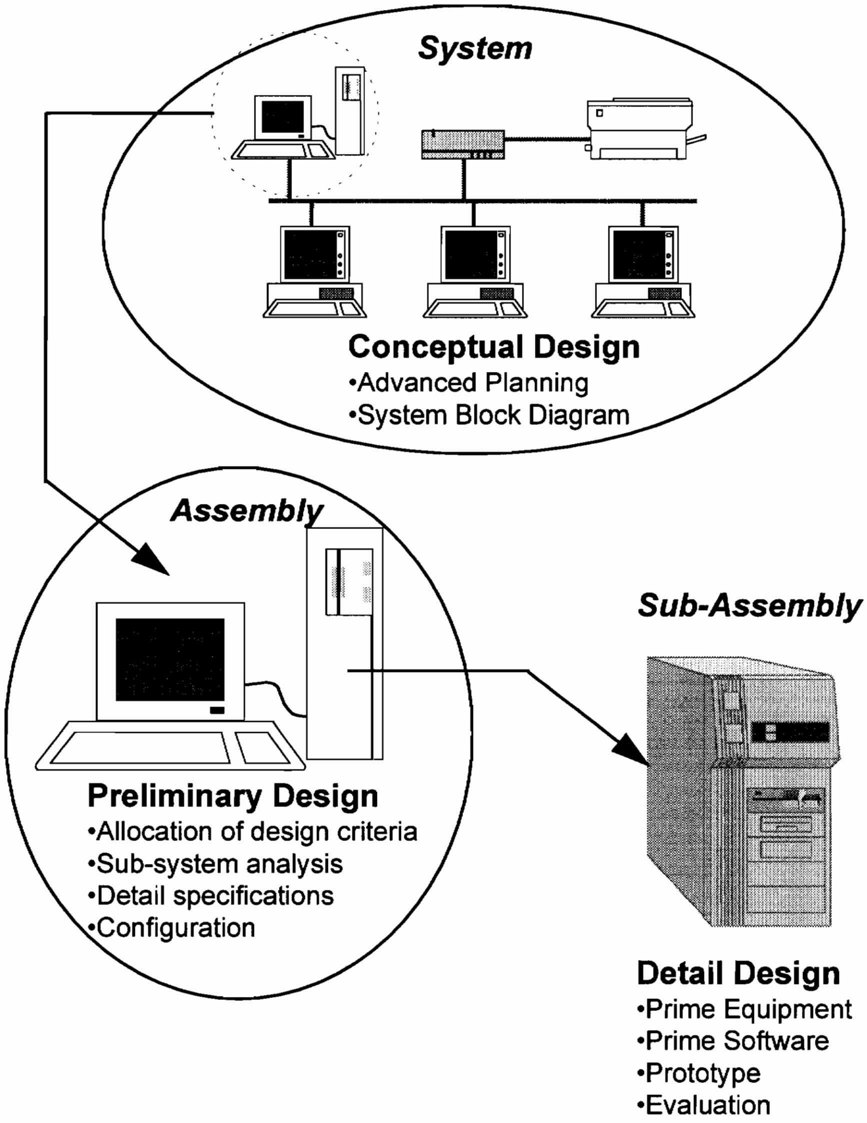
Definitions

To discuss the areas addressed by this study on common ground, certain terms must first be clearly defined. In particular, the reader must understand where the decision to use COTS or custom occurs, and what is meant by the design phases of the system life-cycle. Another expression requiring definition is COTS. The term COTS can have different meanings to different groups in the Government systems arena. For the purpose of providing an equitable basis for the development of the checklist and weighting criteria, an unambiguous definition for this term must also be furnished. Finally, the word "failure" can mean many degrees of non-performance to operational specifications. This term will also be examined and defined.

Design Phases

Three different design phases are part of every system life-cycle. These three are the conceptual design, the preliminary design, and the detail design phases. Figure 1 illustrates these three phases of the system's design. The system illustrated is a small computer network. Beginning with the conceptual design phase, the system requirements are examined at the highest level and allocated down through the preliminary design phase to the sub-system, and finally to the assembly or sub-assembly level in the detail design phase.

[2] Andy Liverman et.al., *American Defense Preparedness Association Commercial-Off-The-Shelf (COTS) Supportability Study*, (Fairfax: American Defense Preparedness Association), p. 9.



Design Phases

Figure 1

In the conceptual design phase, system operational requirements and maintenance concepts are established. A block diagram of the system is created in order to assign attributes, specifications and major functions. Advanced product planning is also performed, providing the framework for structuring and ranking selection criteria in the next two design phases.

In the preliminary design phase, system functional analyses are performed. A preliminary synthesis of the system design is achieved and the system design criteria allocated to optimize all aspects of the system performance. In the example in Figure 1, certain design criteria have been allocated to the system block which will become the file server. Detail specifications are applied to the blocks, in this case the file server, to meet the customer's performance requirements. Through this process, a system definition is reached, providing the basis for the detail design.

In the detail design phase, detail specifications establish the preliminary design performance and configuration requirements. These in turn lead to the production and/or the construction of the desired system. Included in this phase, is the description of assemblies, sub-assemblies, LRUs, piece parts and consumables, as well as the elements of logistics support. In our example, preliminary performance requirements have been established which will determine the design of the Central Processing Unit (CPU) sub-assembly of the system file server.

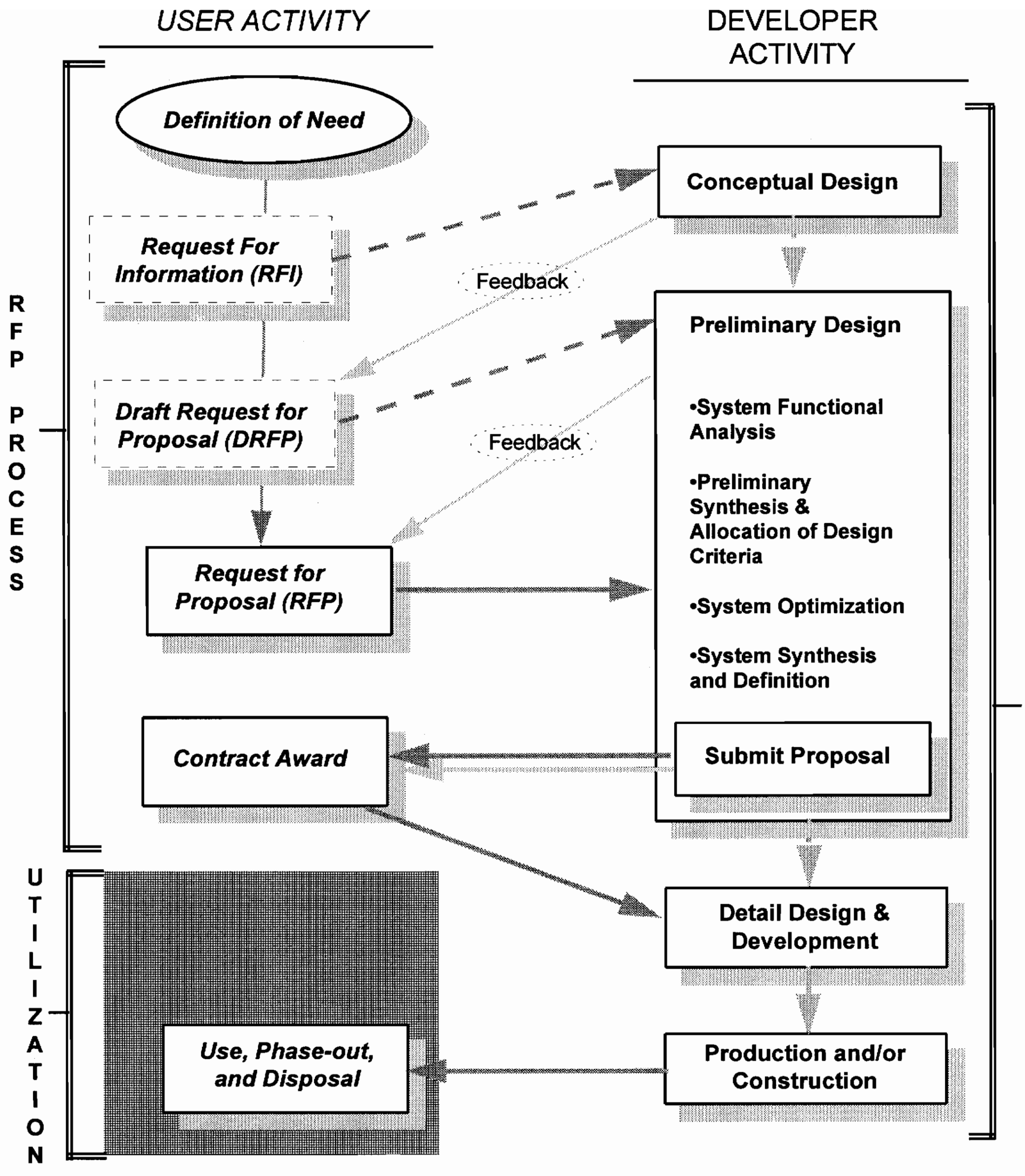
Figure 2 illustrates the system life-cycle from the Request for Proposal (RFP) issued by the Government customer through the acquisition and utilization phases. The illustration is split into two sides: the User Activity and the Developer Activity. The user activity side shows the RFP process and the utilization phase, while the developer activity shows the interrelationships between the RFP process and the system design phases. The RFI and DRFP blocks shown are optional blocks and depend on how well the customer knows their own requirements and the feasibility of a solution. The developer activity concludes with the remainder of the acquisition cycle, including the manufacture of the system.

Figure 3[3] illustrates the design phases of the system life-cycle. The sub-parts of each design phase are shown, and the points at which decisions would be made concerning the use of COTS or custom components are highlighted.

COTS

The term "COTS" is more difficult to define clearly. MIL-STD-2036A

[3] Adapted from Benjamin S. Blanchard and Wolter. J. Fabrycky, *Systems Engineering and Analysis*, 2nd Ed. (Englewood Cliffs, N.J.: Prentice Hall, 1990), p. 22.



RFP/System Acquisition Phase Interfaces

Figure 2

defines COTS as "Item(s) which can be purchased through commercial retail or wholesale distributors as is, for example, equipment that is available as a catalog item."[4] From this definition, it is evident that to qualify as COTS, an item must be designed and available prior to its use on a Government program. Although a multitude of definitions for "customized COTS" exist, this study will avoid that quagmire in an effort to address the problem at hand. For the purpose of this discussion, the addition of brackets or mounting hardware to allow the installation of sub-assemblies into their parent assemblies is not considered customizing. Neither is the addition of an adaptive interface such as a cable or harness that requires little work and is readily available on short notice.

If units are designed for use on a specific Government program but are developed, manufactured, and sold as catalog or commercial items, then they are still COTS. Such items are also defined as non-developmental items, or NDIs. Definitions of NDIs include items which "...require only minor modification to conform to the procuring agency's requirements." and items "...currently produced that do not conform to...(NDI)...requirements solely because the item is not yet in use, or not yet available in the commercial marketplace."[5]

The common denominator in all of these definitions of COTS is that design and development costs of the item are initially borne by the manufacturer or designer. Because of this, the Government cannot influence the design directly, nor can it control the process or the make-up of the final product. To any user, the COTS item is a "black box": desired input(s) to the box produces the desired output. The same definitions apply to software as well as to hardware. What transpires inside the box or program should not matter to the user. Changes in design inside the box may be made to reduce manufacturing or maintenance costs, and the catalogs or sales literature would not even note the difference, since inputs, outputs, and physical features are still the same.

Failure

A final term requiring definition for the maintenance discussions is "failure". Most maintenance activity is predicted based on what is termed a "failure" by the manufacturer. The design engineers and marketing personnel have an entirely different perception of a failure than the customer. As an example, the filter of a certain newly delivered COTS-based piece of

[4] p. 27, MIL-STD-2036A, Electronic Equipment Specifications, General,
[5] Ibid, p.30

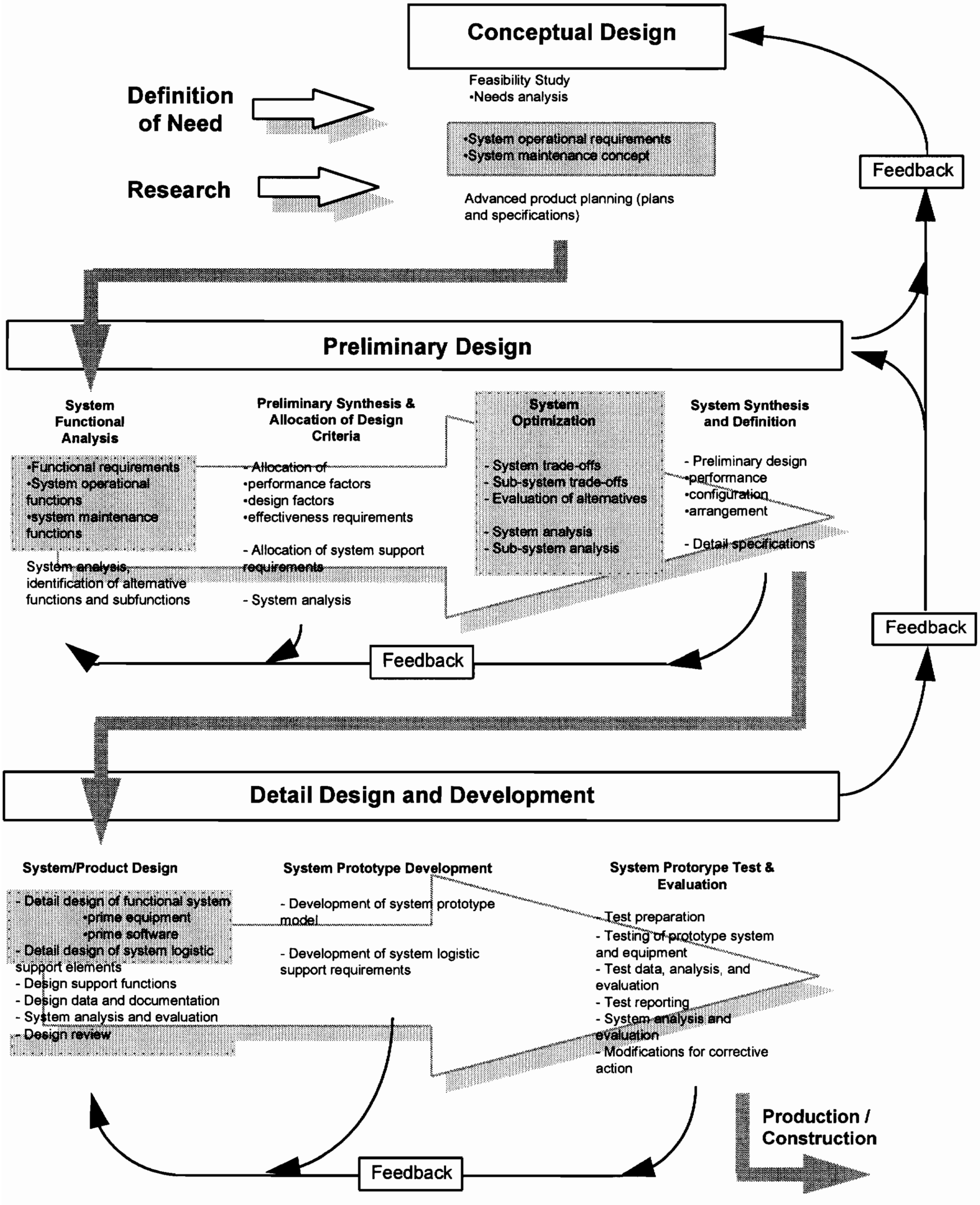
Government equipment was rated at a mean time between failures of 1,250,000 hours (142.7 years at 24 hours/day, 7 days/week). Discussions with the OEM revealed that a clogged filter was not a consideration in the calculation of those numbers. However, for the maintainer, a more realistic figure was in the 5000 hour range. A failure to the maintainer was any unscheduled action undertaken to restore the system to the normal operating state. This activity is not to be confused with preventive maintenance, which is scheduled and does not necessarily correct abnormal performance. Considering this and similar examples, a failure will be defined as: any non-conformance to the system operating specifications which requires unscheduled maintenance activity.

Decision Points

Decision points on the use of COTS versus custom components are scattered throughout the system's design process. They include the conceptual design phase, the preliminary design phase, and the detail design phase. This section will address the components of the decision process in the conceptual and preliminary design phases and demonstrate the impact of these decisions on the detail design phase.

Figure 3 illustrates the conceptual, preliminary and detail design phases of the system life-cycle. As a reference for this discussion, the points at which decisions are made influencing the selection of COTS or custom solutions have been shaded.

A key phase for the determination of whether to use COTS or custom is in the conceptual design phase. It is during this phase that the system operational requirements and the maintenance concept are examined. Based on the projected life of the equipment and the support infrastructure required to maintain the system, a COTS solution may not be feasible due to limitations in the abilities of the OEM, or because of the high costs of OEM supplied maintenance. An example of prohibitively expensive OEM supplied maintenance is in the super computing arena. In this field, a certain manufacturer of some of the world's premier super computers has lost ground to units which, although not



The System Life-Cycle Process (Design Phases)

Figure 3

as good, have provided reasonable performance at a lower acquisition cost, and especially at lower operating and maintenance costs. In one instance, a user of this super computer manufacturer's mid-range unit actually quit using the equipment and had it removed due to exorbitant maintenance costs which only the OEM could provide. This example demonstrates how the decision to use OEM supplied full service maintenance resulted in a completely ineffective system due to the prohibitive maintenance costs. The section on evaluation criteria will examine OEM relations to operational requirements and maintenance concepts in more detail to demonstrate the impact of decisions in this phase.

The conceptual design phase is also crucial for beginning the checklist process. Important parameters can already be determined based on the known customer and system requirements. The early establishment of the weighting criteria will also forestall bias toward any particular solutions, since the checklist criteria will guide the decision process instead of the desired outcome creating the checklist.

In the preliminary design phase (see Figure 3), operational and maintenance functions are defined, and the system-level requirements identified in the conceptual design phase are translated into detailed design requirements. It is in this phase that the trade-off studies and the optimization of requirements occur. Functional flow diagrams are also developed to address what will be accomplished by the various components of the proposed system. These activities result in detailed specifications that will be utilized in the detail design phase. The decisions made in this phase can further restrict the choice of COTS alternatives or may define COTS as the only solution. Operational and maintenance functional requirements in particular will restrict the solution, or provide weighting criteria inputs to the checklist developed in this study.

COTS Evaluation

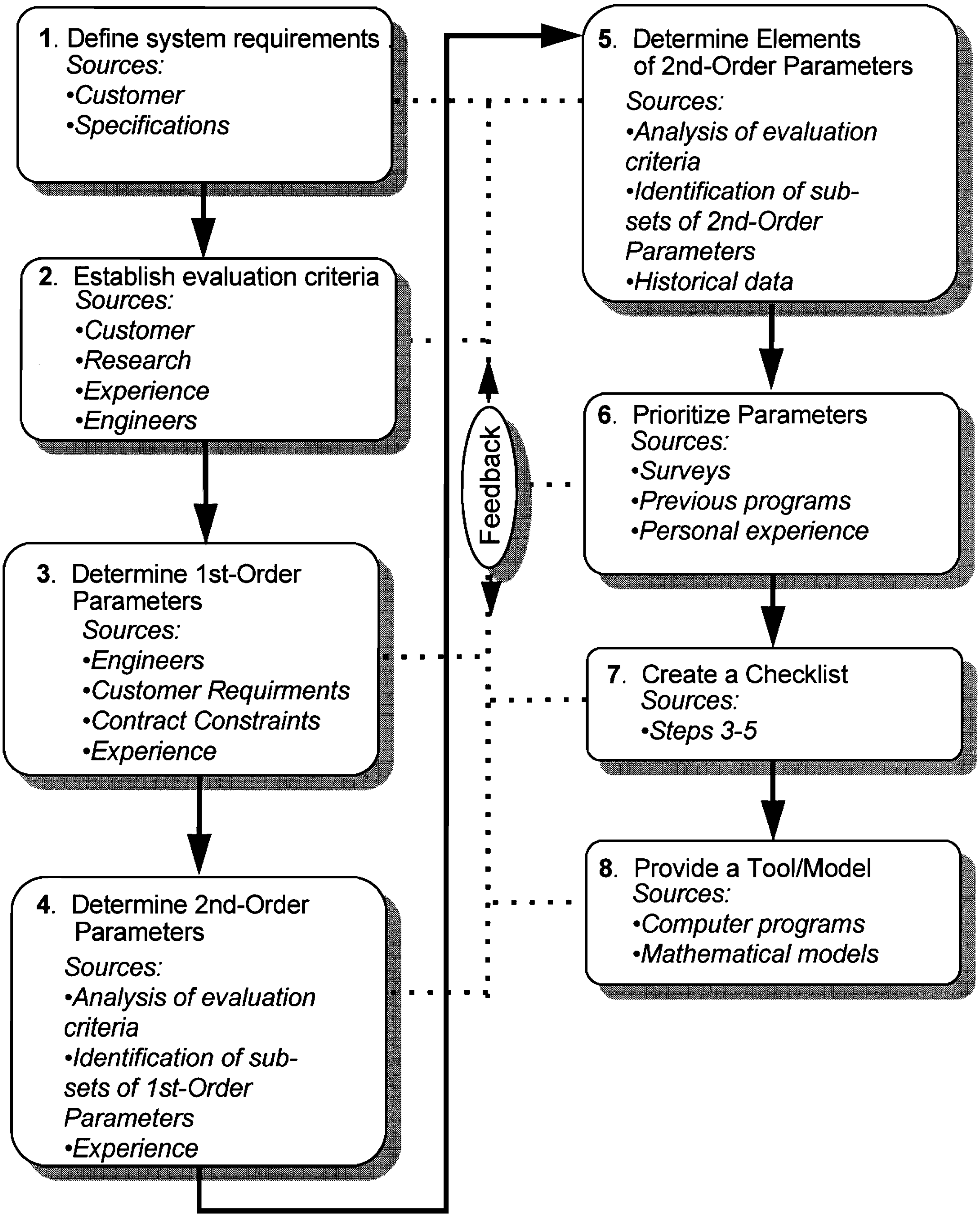
By following the simple eight-step process outlined in Figure 4, a checklist or set of evaluation criteria for a system is developed. The first step, as illustrated, is to identify and define the system requirements. Sources of data which provide this definition include the specifications provided in an RFP (see Figure 2) as well as customer-provided input. A special effort should be made to ensure that the customer, in this case the Government, clearly understands what they really want. These system requirements, combined with a company's program management and engineering experience lead to the establishment of evaluation criteria (step 2). Out of these evaluation criteria, the first-order parameters are selected. First-order parameters will provide the basis for a final selection criteria, and are factors which are not a subset of any other measure. Again, engineering and program management experience, customer requirements and contractual constraints provide the justification for the selection of these parameters.

Second-order parameters are a sub-set of the first-order parameters. They are composed of the data elements which must be determined to provide a complete first-order parameter. By combining experience with an analysis of the components of the first-order parameters already established, the sub-sets of data which comprise the second-order parameters can be identified (step 4). These sub-sets of data may contain further sub-sets (step 5) which could be called a third-order parameter. Again, an analysis of each second-order parameter combined with past experience will determine if it is a discrete data point or if it contains additional elements.

Steps 3, 4, and 5 of Figure 4 can occur in a linear fashion from the top down (step 3, then 4, then 5), or from the bottom up. Since the data sets are all related, it is more likely that this process will move forward in parallel, with first and second-order parameters and their subsets determined simultaneously. The lowest data elements in each first-order parameter category will lead to the questions which must be asked to fulfill the data requirements and complete the checklist.

Step 6 is to prioritize the parameters which have been established. In this study, a survey of personnel familiar with the design process was used to establish the hierarchy between the first-order and some second-order parameters (see Appendix A). Since surveys are not always practical or timely, the personal experience of someone such as a program manager or system engineer can be utilized in the prioritization process. Ideally, the finalized, prioritized list along with the justifications would be entered into a data base for reference on future programs.

From these prioritized parameters, a checklist similar to the one in this study would be developed (step 7). A computer program or a mathematical



Evaluation Process

Figure 4

model (step 8) would be a benefit, although not absolutely necessary in the execution of the evaluation of alternatives.

In this study, the first seven steps of the process were followed. Since no program or contract in particular was selected, steps 1 and 2 were generalized. The resulting checklist is thus an inclusive one which could apply to most programs or contracts.

Advantages of COTS

Why use COTS components in the design of systems? Discussions with Government representatives for large system integration programs disclosed that the current shift to COTS was driven by the perception of savings in system design, purchase and maintenance costs, as well as the reduced system procurement and acquisition time. Annual maintenance costs in particular were high on the list of reasons to utilize COTS products. An example given by one Contracting Officer's Technical Representative (COTR) was, that for one system supported, projected maintenance savings alone would pay for a newly installed COTS system in less than two years. Following the payback period, maintenance was projected to cost one third of the previous custom system's maintenance, while savings in operating costs were also expected due to reduced manning requirements.

A number of factors lie behind these perceptions. There are advantages to utilizing COTS products, but these advantages do not come without a price. What the systems engineer and design engineers must do is weigh these factors to decide if commercial products can meet their customer's requirements.

The primary advantages to the use of COTS include:

- savings in research and development (R&D) costs
- reduced time to market
- high reliability
- lower unit cost
- lower maintenance costs

These advantages will be discussed in the remainder of this section.

Research and Development Cost

In the research and development or design phase, the cost savings are based on the established existence of required items. Since COTS items are already designed, the R&D costs do not appear as a separate, distinct cost factor. Rather, they are imbedded in the price of the COTS component by the manufacturer, who projected the number of units which could be sold and the price required to recoup his development, manufacturing, marketing and other costs. Normal market forces limit the price of such an item, thereby also limiting allowable R&D costs. The R&D costs are diluted for each purchaser, since all buyers of COTS equipment share the R&D costs through the purchase price.

Reduced Time to Market

Another advantage to the use of commercial products is that they are readily available with a relatively short acquisition time. As detailed in the definition section above, COTS is usually available or already in development by the time it is needed for a Government system. This reduces or eliminates the development cycle, thereby reducing the overall time required to design a system which satisfies the requirements identified by the Government customer. The DATSA B-1 automated test equipment design by Emerson Electric for the U.S. Air Force had a development cycle in excess of two years. This system was designed and built in the mid-1980s and was a custom system using a minimum of COTS components. Contrasted with that are the currently proposed high-powered supercomputing centers for the Department of Defense that have a developmental cycle of 10 months and specify maximum use of COTS. This 10-month cycle includes the solicitation and request for proposal.

The trend in Government programs is also toward firm fixed price (FFP) contracts, even for large programs with stringent requirements. The near immediate availability of COTS products and the catalog pricing for these items reduces the risk to the contractor of underestimating the development and manufacturing costs for assemblies, subassemblies and software.

Reliability

A major consideration in the selection of any system component is its reliability. An advantage of selecting COTS units is an inherently high reliability for most items. Due to the nature of COTS and its relatively high production numbers, a company cannot afford to produce units with a low reliability. The number of warranty repairs and attendant customer dissatisfaction can and has put companies out of business. To illustrate this, let us examine a common 200 Watt power supply for a personal computer (PC) on a medium-size network of 150 PCs with a 12-hour duty cycle. Assuming that the power supply was designed for a Mean Time Between Failures (MTBF) of 5 years in this situation, the MTBF would be:

5 years x 12 hours/day x 5 days/week x 52 weeks/year = 15,600 hours

The failure rate (λ) would then be 1/MTBF, or:

1/15,600 hours = 0.0000641 fails/hour

Annual operational hours for the network are:

150 PCs x 3120 hours/PC = 468,000 hours

Assuming a fairly standard one-year warranty is supplied by the manufacturer, these numbers result in 30 failures in one year.

0.0000641 failures/hour x 468,000 hours = 30 failures

This means that the manufacturer would be expected to repair or replace a mean of 30 power supplies, or 20%, for this one user alone. Obviously, this is not good business. As a result, manufacturers of COTS equipment usually design a robust, highly reliable unit. In the example of our PC power supply, the actual MTBF supplied by one manufacturer was 70,000 hours.[6]

Low Unit Cost

As discussed in the above section on research and development, the unit cost for development is low because it is distributed across the entire market base for the product. The purchase price of a COTS item is also less expensive

[6] Silicon Graphics, Mil-Std 217 data for P/N 9430812, 250W, 74 Amp AC/DC 3-Output Power Supply. Data supplied on 1/25/94 by Heather Cohen of Silicon Graphics, Inc. 15280 Addison Rd., Suite 130, Dallas, TX 75248

because of volume. Through economies of scale, the manufacturer can realize cost savings in the manufacturing run. When compared to the limited lot size or quantity of custom equipment, the manufacturing costs per unit item are much reduced, resulting in a lower final product cost. This lower cost of assemblies and/or sub-assemblies will reduce the final manufacturing cost of the entire system, as well as reducing the cost of spares procurement.

Reduced Maintenance Cost

Maintenance costs for COTS products are lower for a number of reasons. Among these are the higher reliability mentioned earlier, the relatively large population of virtually identical equipment which must be supported, and the competition from third-party maintenance suppliers. Another factor that helps reduce the maintenance cost is the rapid rate of technological advances. Because of this, equipment is usually obsolete before it even gets to the back side of the "bathtub curve," Figure 5. Once there, however, reduced

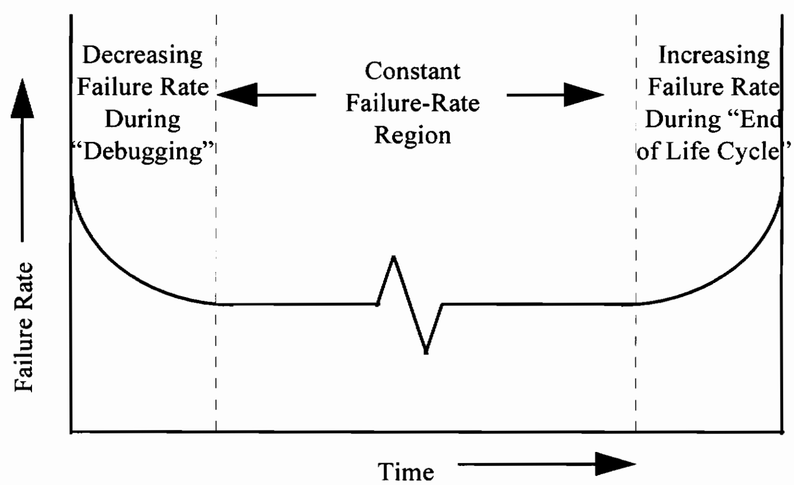


Figure 5 [7]

Typical Failure Rate "Bathtub" Curve

maintenance costs are perpetuated through the low cost of purchasing used equipment to stock spare and exchange pools. During the middle of the life-

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[7] Benjamin S. Blanchard and Wolter. J. Fabrycky, *Systems Engineering and Analysis*, 2nd Ed. (Englewood Cliffs, N.J.: Prentice Hall, 1990), p. 355.

cycle, when the failure rate is at its lowest, the maintainer can use the inherent reliability to assess the risk of offering low cost maintenance. By calculating the probability of mission survival and knowing the base of equipment supported, the maintainer can estimate the number of service calls required. Again, because of the large population base, the costs of service personnel, training, spares, travel and facilities are reduced for each individual user. Consider our power supply example in the previous *Reliability* section: assuming this unit had special features requiring additional skills to troubleshoot and repair, and a single service call involved 3 man-hours of field service time, the 30 annual predicted failures would consume 90 man-hours of time in intermediate maintenance, not nearly enough to keep a single technician busy. However, with a larger customer base in a regional service zone, economies of scale would allow the same technician to handle a unit population base in excess of 3600 units, with less than a 50% probability of another failure occurring while attending to a previous failure.[8]
A criterion for the selection of COTS then is the requirement for a low-cost, highly reliable unit. Weighting of the reliability factor must be fairly high to offset the maintenance difficulties that may be encountered when the systems are retained long past their obsolescence.

Disadvantages of COTS

The advantage of using commercial products in the design of customized systems does not come without a price. There are certain advantages to custom designed and manufactured systems, and corresponding disadvantages to the use of COTS items. These disadvantages can include: lack of a full drawing package; short manufacturing life-span; OEM changes/improvements to the selected model; poor design for supportability in Government programs; and incomplete or erroneous maintenance data. These points are addressed in the remainder of this section.

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[8] Assuming a labor-year of approximately 2000 hours, with 3 hours per service call, 667 failures could be serviced per year. Using the reliability equation $R=e^{-k\lambda t}$, setting R = 50% , λ = .0000641, and t = 3 hours; and where k = the number of units which would operate successfully with a 50% reliability for the 3 hours required for a service call. By this calculation, k = 3604.

Lack of Drawing Packages

The lack of drawings and poor long-term supportability are closely related. Many COTS items are over designed for robustness because there is no intent to repair failed units. Unfortunately, when the model production run ends, an item is no longer available, complicating the procurement of replacement units. If, as is the case with most Government programs, the unit continues in use for many years, it will be difficult or cost prohibitive to repair or replace any failed units. Without proper evaluation and pre-planning, this situation could nullify any cost advantage derived from the use of COTS. The possible need to stockpile whole units as spares for non-repairable items could make the COTS alternative uneconomical, depending on the unit price.

Short Manufacturing Life-Span

Short manufacturing life-span also affects the supportability of fielded equipment. If COTS sub-assemblies are selected in the design of a system and the manufacturer of the sub-assembly ceases production of the selected design in the middle of the assembly production run, the plan for supportability must also be altered. Not only is it possible then to have fielded assemblies with different sub-assemblies, but any repairs for the out-of-production units may require special handling. There are other factors however, which would mitigate the effect of such a change. These include selection of items with common or industry standard interfaces for ease of interchangeability, a standard size, and/or common mounting hardware.

OEM Changes

Changes or improvements by the COTS manufacturer also pose a threat to the integrity of the design and the equipment supportability. Since the purchaser of the COTS equipment has little influence on the design other than through normal market forces, the COTS manufacturer can alter the design to "improve" their product at will. These same improvements, although beneficial to the majority of existing user and attractive to potential buyers, can cause some existing users a number of problems. These include: interchangeability, stocking of multiple parts for manufacture and maintenance, and complication of configuration tracking data. The interchangeability issue is the same as that faced by a short manufacturing life-span. It may or may not be necessary to stock both old and new units, depending on the degree of interchangeability of the new with the old. Tracking of the next highest assembly configuration, if required, will become more difficult in all cases but those of 100% interchangeability. There will now be two possible configurations for the next highest assembly, and as other COTS components change, the system maintainer will have even more configurations to track.

Another risk is posed by "transparent" changes made by the OEM. For users pushing the envelope of performance of the COTS products, as Government users usually do, the seemingly innocuous "transparent" change can have undesired effects on system performance, interfaces with other units, and maintenance activity. In one instance, the OEM changed commercial power supply vendors mid-way through a program. The new vendor built the power supplies to a generic specification instead of the program unique specifications that called for special mounting holes and inserts. The end user was unable to mount the power supplies in the system, which led to a severe shortage of these units until the mounting holes and inserts could be added and the vendor process corrected.

Worse than hardware interchangeability problems is that of software. A change to a COTS software program used on a large-scale integration effort with customized software interfaces can cause errors or changes to operating procedures that may take weeks to fix or adjust to. The COTS software program is the property of the manufacturer, who is under no obligation to provide further changes to accommodate the system integrator's custom software interfaces. An example of such a change is given whenever Microsoft releases a new version of their Windows or Office programs. Subtle changes in how to do things the user thought they knew are extremely frustrating. Some functionality may even be lost with the new version. The latest revision of Excel eliminated the ability to “double-click” on a cell and automatically follow the equation back to other referenced cells in the spreadsheet. For those who utilized this feature to track down errors in formulae, its loss was disruptive to their productivity.

Poor Design for Supportability

Although not always the case, COTS equipment is frequently built as or of disposable units, with no intent to repair. This statement is more appropriate for consumer items, but it still has a bearing on the selection of any COTS item. Considering the duration of the life-cycle for Government equipment, the fact that an item is disposable may have a tremendous bearing on the supportability of that item after its normal commercial life-span has passed. The example used below demonstrates how the failure of one item no longer supported can cause the failure of the entire system.

> *Example*: The memory boards in a personal computer are generally considered disposable if they fail. Presently, the rate of technological change for the semiconductor memory in personal computers is estimated to be 1 to 2 years/generation.[9] Assuming a normal Government equipment life-span of 20 years, memory boards might be obsolete and difficult to procure replacements after only 4 or 5 years. Thus, it may be impossible to repair an entire workstation short of cannibalization in the event of a memory board failure.

Incomplete or Erroneous Maintenance Data

Getting accurate maintenance data from a COTS equipment manufacturer can be a problem. Frequently, sales or marketing figures presented to buyers are incomplete, or have caveats on the source or derivation of the data. A specific example of maintenance data that is critical to the calculation of life-cycle costs is failure data. It is not unusual to have certain types of failures not included in the total failure rate or MTBF. A good example of this is the failure rate of PCs. One manufacturer contacted only included what they termed as "critical" failures. These included such items as power supply failures, motherboard failures, and memory failures. They did not include monitors, keyboards, or mouse failures, any one of which would eliminate that PC as a functional unit.

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[9] Liverman et.al., *COTS* , p. 6.

Another recent example of deceptive or incomplete reliability data involved two integrated circuit (IC) manufacturers. Both manufacturers produced ICs with virtually identical performance characteristics. Manufacturer B, however, claimed a slightly higher reliability and a lower cost per unit. Further investigation determined that manufacturer B performed accelerated life-cycle testing at 45 C (113^{o} F), while manufacturer A performed the same testing at 87 C (156.6^{o} F). In actual field use, the aluminum metalization of manufacturer B failed much more frequently than the gold metalization of manufacturer A.

As demonstrated by these two examples, the accuracy of maintenance data can frequently be called into question, and may not reflect actual field operating equipment. Mitigating factors for this problem will be presented in the early part of the Checklist section on page 31.

Supplied MTBF data should be based on actual equipment failures in the field. Such failures are a much better indicator of projected unit availability and reliability than typical Mil-Std-217 calculations. This does not mean that calculated failure data has no value,[10] it merely means that a weighting factor must be applied to compensate for any MTBF data derived from a source other than actual usage. This weighting factor will also ensure that comparisons between similar units with different sources of failure data are compared equally.

Required Data

In order to properly evaluate a COTS alternative for a Government program, certain data is required. Effectively, a trade-off analysis is performed between the known data for a proposed design and the commercial alternatives. A certain minimum amount of data is required to perform such an analysis. This data is presented in this section, along with a detailed explanation of each data element and the reason for its inclusion in the list. The required data is presented in three groups: technology data, unit data, and supplier data.

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[10] A comparison of proprietary Mil-Std-217 calculated failure data against 7 years of actual failure data for custom equipment performed in 1986 and 1993 respectively demonstrated that the system-level MTBFs were within 3% of each other.

Technology Data

Prior to the evaluation of various COTS or custom alternatives, some information must be known about the technology under consideration. Although this data will not result in a weighted criteria, the information provided may eliminate either COTS or custom developed items from the evaluation process. These data include:

- Maturity of technology
- Flexibility/Adaptability
- Quantity of users
- Sources
- Rate of technology change
- Expected technology life-cycle
- Compatibility

Maturity of technology: The maturity of the technology embodied in the commercial items being analyzed is an important area of consideration. In our previous discussion of a selected item of hardware, namely a power supply, the technology embodied can be considered mature: it has existed for a long period of time, the basic components of the design have not changed radically, and the changes which occur are driven by improvements to the reliability, manufacturing process, and reduction in size. Another example is the personal computer: although they are constantly changing, changes are driven by the search for faster, smaller units with improved performance, memory, and reliability. The basic design of a desktop personal computing station is well defined in terms of a fairly standardized layout and basic performance parameters. On the other hand, if the requirement is for a high-speed interface between different operating systems, it may be feasible, as of the writing of this paper, to design a custom unit competitive with the commercial ones presently available. The maturity of the technology being evaluated or proposed then is a key factor to use as an initial yardstick to gauge the feasibility of a commercial alternative. This same evaluation holds true for software as well. If the technology under consideration as a problem solution is mature, the feasibility of a custom solution may be eliminated. To be competitive in a mature market is difficult, especially when, as in the case of a large system integrator for the U.S. Government, the technology under consideration is only a sub-set of the final product.

Rate of Technological Change: A risk factor in the selection of any new solution is the present or anticipated rate of technological change. Because of the Government's tendency to use systems for up to 20 years,[11] the present technological growth rate in certain areas presents a problem in both the design and the maintenance of systems. The design effort could be at risk because the product may be obsolete before it reaches the end Government user, while maintenance of a system for 15 years after obsolescence presents obvious logistical difficulties.

As an example of the design obsolescence issue, the Consolidated Automated Support System (CASS) utilized by the Navy and in modified form by the Air Force for the maintenance of avionics, is a custom designed piece of automated test equipment (ATE) whose design effort began in 1976. This highly versatile tester "hit the Fleet" in 1994 after nearly 20 years of development. Over 2 million lines of code support this tester.[12] Now, COTS testers with nearly the same capability, based on a 486 or Pentium PC, are available at one-tenth the cost of a CASS.[13]

A measure of the rate of technological change by years/generation would anticipate some of these problems. Obviously, the CASS is a fairly extreme case, however, any technological changes, as well as the rate of change must be evaluated. If the solution to the problem has already been selected to be COTS, the rate of technological change is a moot point in terms of evaluation criteria, and only serves as a factor in modifying or executing the maintenance concept.

Flexibility/Adaptability: If the technology is relatively new, its flexibility or growth potential should be evaluated. Good growth potential would indicate that better replacement units at a lower cost could be available in the near future, reducing maintenance costs and offering the potential for system upgrades and improved performance.

Expected Technology Life-Cycle: In Government programs, where unit life-cycles average 20 years, the projected length of the technology life-cycle is

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[11] Liverman et.al., *COTS*, p. 7.
[12] Henry Oman, "New Commercial Off-the-Shelf-Testers are Automatic and Intelligent," *IEEE Aerospace and Electronic Systems Magazine*, January 1995, p. 4.
[13] Ibid, p. 5.

also an important consideration. Technology which has a short life-cycle will cause support problems because of the technological obsolescence of the units supported, requiring large one-time buys to support the expected system life-cycle. There is also the risk that newer, better, less expensive technology arriving on the market after the detail design phase but before the beginning of operations could make the customer feel they were not getting the best solution to their requirements. In some cases, however, this is unavoidable, and it is best to just drive the proverbial stake into the ground and maintain good communications with the customer so that they understand the decisions made.

Compatibility: It can safely be assumed that the compatibility of the custom solution to the remainder of the system is very good, since it is being designed with interfaces in mind. COTS products may or may not present the same degree of compatibility. Modifications may be required in the form of special mounting brackets or cabling for hardware, while software operating systems may require the creation of a custom interface. Cost savings can quickly be eaten up by modifications, and the anticipation that any vendor modifications in the future may require modification of the interface. The standardization of the interface is evaluated in the "Unit Data" category of first-order evaluation parameters.

Sources: A general idea of the number of suppliers provides a good indication of the competition in that technological market. A large number of suppliers would probably indicate a good value for the product price and lower maintenance costs. Unless profit margins are also unusually high, many supplier would indicate that a COTS solution would be more feasible than a custom one. The number of suppliers for a proposed commercial solution provides some indirect effects on cost, service, and other factors driven by competition. The greater the number of available vendors, the better the chance that a solution meeting your criteria can be found at a reasonable cost.

The data elements listed above should be evaluated before any other design decisions are made, since the resulting information could prevent false starts chasing solutions which are not realistic.

Unit Data

Individual units or items within the system have unique evaluation data that is not associated with the system, but with the individual item under consideration. This section lists the minimum items of data about a unit or item which should be available to perform a valid make/buy decision. This unit data can be broken down into three more categories. These categories are: technology information; performance information; maintenance information. At a minimum, the following items of data must be known to perform a valid comparison:

- Unit/Item cost	- Diagnostics/Testability
- Repair/replacement cost	- Calibration requirements
- MTTR	- Performance specifications
- MTBF	- Physical specifications
- Use requirements	- Projected life-cycle
- Compatibility	- Adjustments/Alignments
- Interchangeability	- Preventive maintenance requirements

A short description of these data elements is provided in the listing below:

Unit/Item Cost: This is the purchase price of the unit or solution under consideration. This element applies mainly to COTS products, and will be used in generating the life-cycle cost.

Diagnostics/Testability: This information is based on observation of the actual unit. With the diagnostics and testability in mind, the unit's MTTR should be evaluated for realism.

Repair/Replacement Cost: Repair cost is for COTS items is some fraction of the purchase price, and also usually a fixed price rather than time and materials. The inverse is generally true of custom units. Replacement cost is likely the same as Unit/Item Cost described above.

Calibration Requirements: These requirements are the frequency and measures to which the unit must be compared to maintain peak operating efficiencies.

MTTR: Mean Time To Repair. This number, in hours and fraction of hours, should include the time required to diagnose the problem and restore the system to full operations, not just the time to replace the affected unit. See discussion of MTTR in the Evaluation Criteria section under Maintainability .

Performance Specifications: These specifications are the operating parameters, input requirements, and output of the solution under examination.

MTBF: Mean Time Between Failures. This number is the inverse of the failure rate, and is the operational hours between unscheduled maintenance actions. See discussion of MTBF in the Disadvantages section on Incomplete or Erroneous Maintenance Data.

Physical Specifications: These specifications are the external dimensions, weight, and any other measurements required to evaluate the operating space of the equipment under investigation.

Use Requirements: This measure is the performance requirements derived from the customer requirements, allocated and mapped to the particular item under evaluation.

Projected Life-Cycle: The projected life-cycle is the duration of time the customer anticipates using the system.

Compatibility: Compatibility is an evaluation of the ability of the item to integrate into the system without any special modifications or interfaces.

Adjustments/Alignments: Adjustments and alignments are performed during maintenance actions to optimize performance. These can range from front panel knob adjustments to trim pot (potentiometer) adjustments, to more sophisticated calibrations requiring specialized test equipment. (see Calibration section on page 38)

Interchangeability: This is an evaluation of the ability of the unit to be exchanged with a replacement unit in a timely fashion.

Preventive Maintenance Requirements: This final data element is an evaluation of the hours required for scheduled maintenance, the frequency with such maintenance will be performed, special tools, and the skill level required to perform the preventive maintenance.

The evaluation of these data is detailed in the Checklist section under the first-order parameters Effectiveness and Unit Data.

Supplier Data

Information about the OEM for COTS units is especially important in terms of the reliability of supplied data and the execution of the operations and maintenance concepts. Usually, information about OEMs is known because of previous dealings with them. If little or no historical information is known, sources of data such as Thomas' Register or Moody's are readily available. The information about a supplier which is required at a minimum includes:

Current financial condition: This information will allow you to anticipate any near term problems with the proposed supplier which may adversely affect the availability of units over the long term, as well as disrupting or altering the proposed operations and maintenance concepts.

Product Experience: The experience the supplier has had with a similar or identical product is a rough indicator of anticipated problems. Logically, experience with an identical product would indicate little or no problems; experience with a similar product would indicate some anticipated problems, and no experience would anticipate some rough spots before the unit got into production. This is not necessarily true, since there are always exceptions to the rule, but generally the conditions noted above can be accepted as a good guide.

Dependability: The history the supplier has of dependability in meeting schedule and performing past contracts is necessary in determining whether they can deliver on the proposed tasks.

Quality: Supplier quality is of obvious importance. It is not enough to have a well-written quality program; adherence to the program and the resulting product are a better guide to real quality. Past customers or market reviews of COTS products are a good source of quality information. When evaluating your own or your anticipated custom solution supplier's quality program or product quality, guard against the tendency to inaccurately judge yourself. A valid solution can only be reached with valid data.

Problem resolution: Supplier responsiveness is important in resolving glitches and minimizing the impact on deliveries and performance. Again, past customers are an excellent source of such information.

Lead times: This parameter becomes especially important if there is a time constraint for the delivery of the contract. Lead times should be readily available from the sales department of the anticipated supplier. It is important that the lead time for the development and delivery of the custom product is estimated as realistically as possible, since one of the major advantages of COTS is time to market, and a realistic delta must be established to assure an accurate evaluation.

Cost control history: Failure to control the cost of any anticipated solution will invalidate the entire evaluation process. Cost control history of both internal and external suppliers of proposed solutions must be known in order to mitigate the risk of invalidating the entire selection process. The evaluator is again cautioned to accurately assess the internal supplier to ensure an accurate comparison can be made.

Existing population: Sales data from the supplier concerning the existing base of similar or identical equipment is useful for determining the maintenance concept, as well as predicting the length of anticipated maintenance support, both from the OEM and possible third party maintainers. For Government equipment which remains in use 2, 3 or even 4 times longer than most commercial equipment, the population base is a good indicator of support resources for hardware in the form of available replacement units from resales, and the repair of failed units down to the component level by third party maintenance. For software, the larger the population base, the more trained personnel are available to continue support.

As noted in most of the above sections, this same information must be provided about the "internal OEM" or the anticipated subcontractor in the event that the decision is made to design/build your own solution. This will allow the evaluation of COTS versus custom on an equal footing.

Evaluation Criteria

The discussions on the advantages and disadvantages of the use of COTS items have provided the background for selecting the evaluation criteria. This section examines subjects which by themselves are neither advantages nor disadvantages, but which must be considered in the evaluation of a COTS alternative. The information provided in this section also differs from the previous section on supplier data by addressing factors that are a function of the specific catalog item under consideration or the proposed custom design.

In considering the life-cycle cost factors of a COTS component, maintainability must play a major role. An initial price advantage realized from savings in the design phase may be negated by costly maintenance. Maintenance costs are driven up by factors such as:

- high Mean Time To Repair (MTTR)
- non-standard interfaces
- poor diagnostics
- high Preventive Maintenance (PM) requirements

The optimum system component from the aspect of maintenance has an extremely low MTTR. This results in minimal manpower requirements for the remainder of the system's life-cycle. A word of caution: the source and method used by the manufacturer to derive the MTTR must be clearly defined. Just as OEM MTBF figures do not always represent all failures, neither do OEM MTTR numbers disclose the entire amount of time required to restore a piece of equipment to full operation. The derivation of MTTR numbers must be specified by the manufacturer. In some cases, the MTTR may be defined as the amount of time required to replace an assembly or sub-assembly after the source of failure has been traced to it and all tools and replacement parts are at hand. In other cases, the MTTR properly includes troubleshooting, replacement, and alignment or calibration of the new component to the system. In the first example, the MTTR figures are obviously misleading and may not account for poor diagnostics or extended set-up time after installation. The full MTTR may adversely impact the system availability and constrain the selection of other system components, to the detriment of system performance.

Additional factors that affect the MTTR include accessibility, ease of adjustment, and ease of alignments. Accessibility should consider the location of the assembly or subassembly with respect to ease of replacement. For example, in the case of a standard width rack mount unit, a standardized slide mount would allow more rapid replacement than customized mounting brackets and hardware requiring exchange with the replacement assembly. Additionally, cabling or other physical interfaces should use a minimum of specialized tools, and preferably use only a standard tool such as a screwdriver.

Ease of adjustments and alignments also have a bearing on actual MTTR time. In the event that adjustments must be made for proper performance of the replacement equipment, as is the case with some electronic gear, the number of adjustments should be minimal, and as independent of each other as possible. The same is true of mechanical alignment procedures. Through the judicious use of stops and presets, such alignments should be minimized.

Non-standard interfaces affect the cost of maintenance by providing an additional, usually custom-made item to troubleshoot. This can increase the MTTR because of additional set-up time, or due to the technician being unfamiliar with the equipment. Replacement parts for the interface may also add cost because the item(s) required are not standard.

Additional maintenance cost is added by poor diagnostics also. It should be apparent that the worse the diagnostics, the longer it will take to isolate a problem in software or hardware. Increased troubleshooting time increases maintenance cost through decreased availability and increased maintenance manpower requirements.

Finally, high preventive maintenance requirements also increase the cost of maintenance for reasons similar to the poor diagnostics. The maintenance manpower requirements are increased to accomplish the required preventive maintenance, while the system availability for operations is decreased.

In addition to maintainability, the supportability of the selected item should also provide a clear advantage. Supportability is a term for the logistical support aspects of the maintenance. In cases where COTS equipment is selected for a system, the supportability considerations extend to the OEM. The supplier end of the spare parts pipeline must be a consideration in the selection criteria to insure that the expense of maintenance does not eliminate any savings incurred at the beginning of the life-cycle.

All of the above mentioned factors can individually drive the cost up and negate the cost savings anticipated from the selection of COTS equipment. These factors will be weighted in the final checklist, and applied to our selection criteria.

Checklist

The evaluation of the COTS alternative occurs in several steps. First, the allocated requirements for the assembly or sub-assembly must be identified. Then, a "straw man" configuration for the item must be created. This creates a benchmark against which to compare possible COTS solutions. The data elements described in the previous section must be collected for the proposed COTS solution. Finally, an evaluation of these elements should lead to the selection of the best overall solution to the requirements. This section provides the checklist and the rationale for each of the above steps.

The checklist provided in this section is a general list of the data required to arrive at a final evaluation between various alternatives, both COTS and custom. Data elements in the checklist were discussed in detail in the section Required Data above. The checklist in Table 1 is the summation of that data.

The actual evaluation of the alternatives occurs after this data has been collected from various sources. There are up to three layers of parameters to arrive at the final decision, depending on the final evaluation category to be addressed. The weighting for the various criteria in these layers was developed through surveys of personnel familiar with Government programs, design and performance requirements, and the customer's expectations. Because of time constraints, a more rigorous analytical approach was not used. Details of the survey, personnel, and the rankings of the various criteria are found in Appendix A.

The weighting criteria for any first-order parameter is applied in the following fashion: The second-order parameters and/or filters provided under the first-order parameter determine the ranking of the suppliers or solution providers from best to worst. The weighting factor is then applied to the inverse of the ranking. For example, if there are 10 vendors, the best with a ranking of 1 would receive a rating of 10 that would be multiplied by the weight of the parameter being evaluated. The worst vendor in that category would receive a rating of 1 which would also be multiplied by the parameter weight. This ranking within categories would occur for all five top level parameters, and the resulting five point scores added. The vendor/supplier with the largest sum would be the selected provider.

Table 1

Checklist of COTS/Custom Evaluation Criteria

First-Order Parameters	Second-Order Parameters	Filter	Ranking	Weight
Life-Cycle Cost			**1**	**4.5**
	Research and Development		n/a	$
	Materials		n/a	$
	Production		n/a	$
	Operations		n/a	$
	Maintenance		n/a	$
	Disposal		n/a	$
Effectiveness			**2**	**4**
	Availability	Yes	n/a	%
	Preventive Maintenance	Yes	n/a	Hours
	Calibration		n/a	Hours
	Maintainability	Yes	n/a	Ranking
Unit Data			**2**	**4**
	Standard Components, I/F		1	9
	Human Factors		2	8
	Projected Life-Cycle		3	7
	Modularization		4	6
	Guaranteed Price		5	5
	Manufacturing Life-span		6	4
	Safety		7	3
	Drawing Package		8	2
	Excess Performance		9	1
System Support			**3**	**3**
	Support Requirements		1	6
	Quality Rate	Yes	2	5
	Turnaround Time		3	4
	Response Time		4	3
	Maintenance Plan		5	2
	Guarantees/Warranties		6	1

Table 1 (continued)
Checklist of COTS/Custom Evaluation Criteria

First-Order Parameters	Second-Order Parameters	Filter	Ranking	Weight
Supplier Rating			**4**	**2**
	Lead Times		1	8
	Quantity Already Sold		2	7
	Cost Control History		2	7
	Problem Resolution	Yes	3	6
	Control of Changes	Yes	4	5
	Current Financial Condition		5	4
	Product Experience	Yes	6	3
	Quality		7	2
	Dependability	Yes	8	1

To successfully accomplish a selection in this fashion, the rating criteria must be established during the conceptual design phase of the life-cycle. The rankings and weighting illustrated in Table 1 and justified throughout the remainder of this study are based on past experience with Government programs. Corporate culture, concepts, requirements or other conditions may change the order or the weighting of this list. The second-order parameter and filters presented in the checklist in Table 1 must be ranked within their own first-order parameter, and those first-order parameters ranked relative to each other by a proposal manager or program manager with an understanding of system and customer requirements.

The final selection of the COTS or custom solution is based on the previous discussions presented in this study and additional criteria, ranked and weighted in the four primary categories which form part of every life-cycle analysis, plus one more category for supplier rating. These five categories and their weighting are shown in Table 2 below. The five categories were ranked for their relative importance, based on the research presented in this study and the references used in the research. A brief justification for the ranking follows.

Life-Cycle Cost

According to the survey results (Appendix A), unit data (listed in the survey as performance) was first, followed closely by effectiveness, then life-cycle cost. Considering the background research performed, the order of these three items was reversed and the weighting structure changed to reflect the relative importance of the items. However, because the results of the survey can not be ignored, the weight of the life-cycle cost category was only differentiated from the unit performance by half

Table 2
First-Order Evaluation Criteria

First-Order Parameters	Ranking	Survey	Weight
Life-cycle Cost	1	2	4.5
Effectiveness	2	1	4
Unit Support	3	3	3
Unit Data	2	1	4
Supplier Rating	4	4	2

of a point instead of a full point.

Life-cycle Cost was awarded the highest weight. The basis for this weight is the Pentagon's own insistence since the mid-1980s that the bottom dollar is the best value,[14] as well as a section in the Federal Acquisition Regulations (FAR) subpart 15.605 (c) which states:

"While the lowest price or lowest total cost to the government is properly the deciding factor in many source selections....the government may select the source whose proposal offers the greatest value to the government in terms of performance and other factors....".[15]

In the few (13) proposal efforts that I have supported, all have been awarded to the lowest bidder. In at least three of those 13 awards, the winner was unable to immediately meet the technical requirements. Clearly, in spite of

[14] Herbert J. Coleman, "U.S. Military Competitive Buys Affect International Negotiations," *Aviation Week & Space Technology*, December 1985, p. 25.
[15] Ibid, p. 25.

current protestations of rating technical merit first and cost last, the Government still assesses the most weight to the lowest cost.

The second-order parameters for the Life-Cycle Cost category are similar to those used in a proper System Life-Cycle Cost analysis. They include Research and Development/Design (R&D), Materials, Production, Operations, Maintenance, and Disposal. However, when evaluating second-order

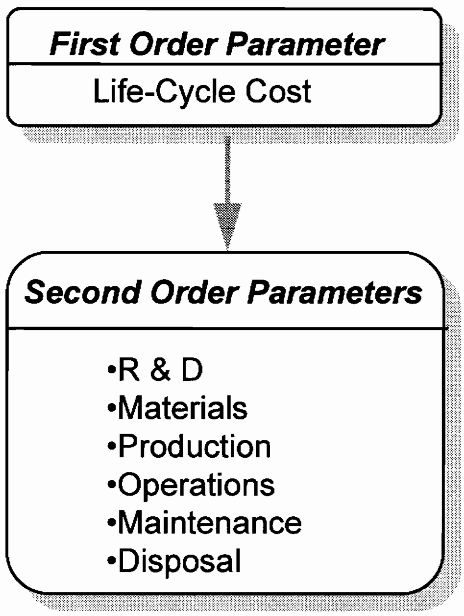


Figure 6

Evaluation Category: Life-Cycle Cost

parameters for the life-cycle cost, it is important to remember that these components of cost apply to the individual unit or sub-assembly under consideration, and no more. Second-order parameters that provide the basis for the final evaluation of life-cycle cost include at a minimum the following components:

- *Research and Development (R & D)*: These costs are normally associated with a custom solution. As stated before, a benefit of COTS is no R&D costs. An accurate estimate of research and design labor and materials should be made, including costs for any prototype and testing of custom units that may be considered.

- *Materials*: Material costs include raw materials or components required to create the various required engineering models, prototypes, and production units, as well as the material cost of specialized equipment needed in the manufacturing process. For COTS products, these costs would include the purchase cost of the item, as well as the cost of any additional hardware or software translators/interfaces. If an entire custom unit were subcontracted, this cost would be the unit cost of that subcontracted item.
- *Production*: These costs would primarily be estimated for a custom solution. For a COTS product, the purchase price, addressed in "Materials" above, already includes the production costs. For custom solutions, production costs could include manufacturing labor, equipment, facility costs, initial logistics support, test equipment and drawing or data packages.
- *Operations*: The operational costs of the assemblies and sub-assemblies evaluated phase should be minimal. They include the operating personnel's fractional time consumed by the unit under study, as well as any utilities consumed. Unless there is a large range in this figure across the population of units evaluated, the operations parameter will have little or no effect, and can then be ignored for the purpose of the COTS/custom evaluation.
- *Maintenance*: Maintenance costs can make up the largest part of the remainder of the system life-cycle cost, if not the largest part. These costs for both COTS and custom equipment include the cost of replacement units or repairs, shipping and handling of repairs/replacements, labor to restore the system; preventive maintenance, cost of maintaining supporting test equipment, upgrades to equipment, cost of maintaining documentation, spares, calibration, and training. The numbers of these cost factors that apply to the various proposed solutions depend on the nature of the solution. For software, neither preventive maintenance, calibration, nor shipping and handling may apply. For various hardware, especially COTS, there may be no training requirement or training available, while for custom units the training may include the detail required for the intermediate maintenance personnel to affect a permanent repair to a field failure.
- *Disposal*: The disposal cost of the individual assembly or subassembly may also be a fairly negligible cost, just as operations might be. However, the disposal costs must be considered in the event that the solution being

considered has special handling requirements. As an example, the disposal costs of a nuclear bench ionizer will be considerably more than that of a conventional electrical ionizer. Again, this cost factor may not apply to something like a software solution, but it must be considered to ensure no major costs affecting the final decision are overlooked.

A number of these cost parameters may not be easy to acquire, especially from COTS providers. In the event that engineering estimates are required, the cognizant engineer must ensure that the basic assumptions used are applied equitably across all items of the population under evaluation. Only in this fashion can a true, unbiased evaluation be made to provide a "best value" solution to the Government customer.

Once the cost figures have been compiled, the item with the best value for life-cycle cost is rated first, the next best second, and so on in descending order of value. The weighting factor is then applied to arrive at a final number for each unit in the first-order parameter "Life-Cycle Cost". An explanation is provided on page 31 for the application of the weighting criteria against the first-order parameters.

Effectiveness

Closely linked to the "best value" is the system effectiveness parameter. This measure includes the availability, maintainability and dependability of the COTS or custom solution under evaluation. As shown in Appendix A, effectiveness ranked just after specifications (see discussion of re-ordering on pages 34 and 55). It is noteworthy from the survey which groups rated which criteria high on the list. Notably, the design engineers and production groups ranked effectiveness first, while the maintenance personnel rated it a close second behind the ability of the equipment to perform to the required specifications.

The second-order parameters that support the final evaluation of the effectiveness parameter are shown in Figure 7. They include, at a minimum, the following measures:

- *Availability*: The availability of the item under evaluation can be determined fairly accurately by securing the MTBF, MTTR, and Mean Down Time (MDT) data, as well as understanding the customer's usage requirements. By predicting the number of failures using the MTBF and applying the MTTR or MDT against the total predicted failures, the amount of time the equipment will be unavailable can be anticipated. Using this information and the equipment usage, the availability of the item decreased by unscheduled downtime can be determined
- *Preventive Maintenance Actions*: Preventive maintenance also figures into the final effectiveness and availability computations. The mean preventive maintenance time (M_{PT}) and the $MTTR_{PM}$ can be combined with the frequency of the recommended PM schedule to arrive at a total time during which the item is not available to meet operational requirements. This maintenance, if performed during hours of operational usage, contributes to the equipment unavailability. The total hours of unavailability must be added to the unscheduled equipment unavailability described in the above section to arrive at the total equipment down time.
- *Calibration*: If calibration of the item under evaluation is required, the impact of calibration on availability also be calculated. By knowing the frequency of calibration and the amount of time required, a calculation for down time similar to the previous sections can be performed, and the results added in to the total down time figure. If the calibration cycle requires removal of a unit and replacement with a spare until calibration is complete, the cost of additional spare units should be figured into the life-cycle cost, as well as any charges for calibration performed by an intermediate or depot level maintenance facility.
- *Maintainability*. Unit maintainability is a component that is difficult to evaluate objectively as part of the first-order parameter "Effectiveness." A number of maintenance factors are dependent on the design characteristics of the item being evaluated. These factors include accessibility, ease of adjustments and alignments, diagnostics/testability, and other subtler items such as the labeling of components, standardization of components, and ease of handling. However, the majority of these factors are indirectly evaluated as a part of other first or second-order parameters.

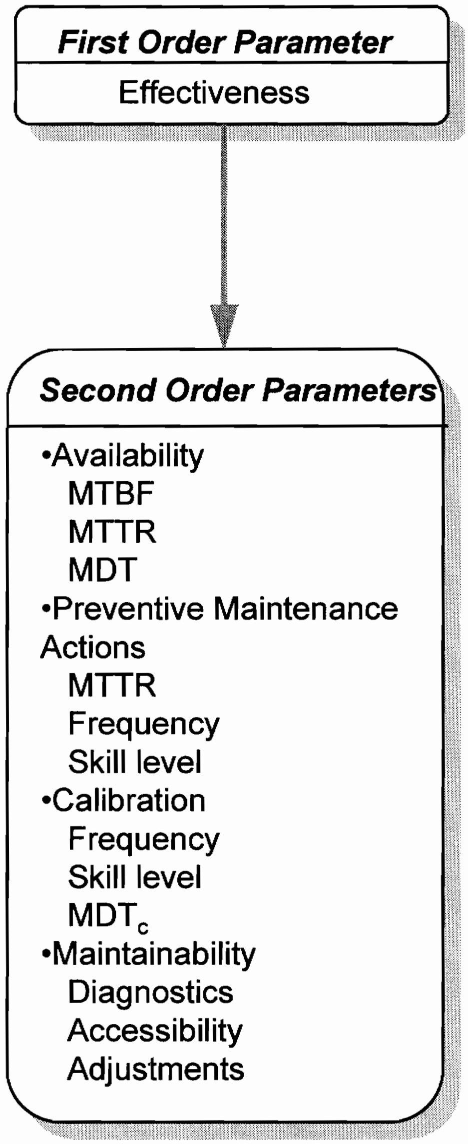


Figure 7
Evaluation Category: Effectiveness

The evaluation of accessibility and ease of adjustments/alignments factors are accounted for in the MTTR for maintenance and preventive maintenance. The unit with the better of these features should demonstrate a decreased MTTR if all other factors are equivalent, thus reducing maintenance labor costs. Ease of handling is also evaluated in cost terms through the price of shipping and handling. Units that require special handling will generally cost more to ship.

The degree of standardization of the unit is accounted for in the section which evaluates the first-order parameter "Unit Data" and is weighted under that criteria.

Finally, good diagnostics and testability of a unit reduce the MTTR by reducing the time required to isolate the cause of malfunctions. Conversely, lack of diagnostics or poor testability may change the entire maintenance concept for the unit, requiring replacement of assemblies at a higher level instead of being able to swap out less expensive sub-assemblies or modules. At the least, poor diagnostics translate into increased man-hours to determine the cause of a malfunction, raising the maintenance manning requirements. At worst, at a later point in the system life-cycle, such a shortage of diagnostics could lead to disposal and replacement of entire assemblies if the OEM no longer supports the older fielded units. The replacement cost can be compared to the repair cost and a monetary value assigned to the life-cycle cost to account for this condition. As mentioned in the section above on life-cycle cost, any engineering assumptions made to anticipate these conditions must be applied equally to the units in the evaluated population that meet the assumption criteria.

The first-order parameter "Effectiveness" then becomes a measure of the item's availability. Although an availability number is probably obtainable from the OEM, the evaluator must resist the temptation to use an OEM provided number as a short-cut. Most vendor provided availability figures do not consider all of the factors mentioned above, and in order to provide a common basis for selection, all evaluations should be performed the same way. The only way of insuring this is for the evaluator to accumulate the data and perform the availability calculation themselves.

Once the effectiveness data has been compiled, the item with the highest effectiveness level is rated first, the next best second, and so on in descending order of effectiveness. The weighting factor is then applied to arrive at a final number for each unit for the first-order parameter "Effectiveness". An explanation is provided on page 31 for the application of the weighting criteria against the first-order parameters.

Unit Data

The first-order parameter "Unit Data" is an evaluation of item or unit unique information and features. This category evaluates the ability of the unit to perform its functions in the context of the system it will be part of and has little to do with the actual performance specifications. I have assumed that if a unit is not within a reasonable range of the required specifications, it will be eliminated from the evaluation process. Thus, unit data is more a measure of the features associated with the unit than actual performance specifications. Figure 8 illustrates the second-order parameters for "Unit Data" that are detailed in the list below. These evaluation criteria are the data elements for the unit or solution under investigation. Some of the elements listed may not initially seem to apply to the level or category assigned, but the detailed explanation of the data elements provides the justification for the relationships.

- *Reliability*: The measure of a unit's reliability is one of its most important parameters. The item under consideration must be reliable, otherwise the other features of that item will be rendered useless. If the other designed features cannot be exercised because of poor unit reliability, then they are moot. The analogy to this is the fully loaded automobile which spends much of its time in the shop for electrical problems: there is never an opportunity to exercise all of the features because even the basic components do not work.
- *Standardized Components/Interfaces*: Interchangeability of a unit with other "standard" market products potentially provides more ways to get items repaired or replaced without relying on the OEM, while standard interfaces allows easy integration into the system without special rework or effort. One of the benefits of COTS mentioned earlier was the market-driven standardization of units to allow interchangeability. The IBM PC clone is a classic example of this type of situation. The ability to select from more than one supplier for future replacement components and parts without doing any modifications is of obvious benefit to the maintainer.
- *Human Factors*: An important but often ignored second-order parameter is that of Human Factors, or the man/machine interface. A COTS or custom

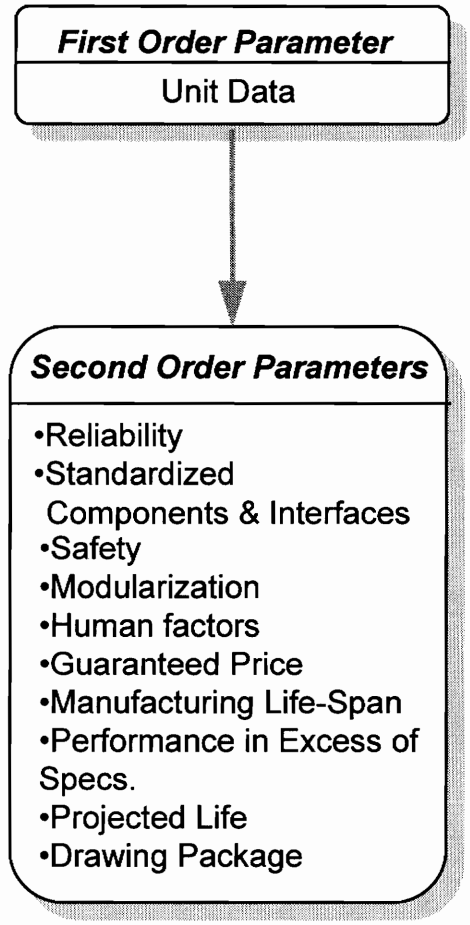


Figure 8
Evaluation Category: Unit Data

solution designed with the operator in mind and with easy-to-use and/or understand features built in reduces operational costs. This cost reduction is accomplished through a shorter learning curve, lower operator error rate, and even reduced operator fatigue, depending on the item under evaluation. For these reasons, Human Factors ranks high in our Unit Data parameter.

- *Projected Life-Cycle*: In Government programs, where unit life-cycles average 20 years, the projected length of the unit's life-cycle is also an important evaluation parameter. Items that have a short life-cycle will require early replacement in the system, with the attendant procurement and interface problems for equipment which in all likelihood is already obsolete.

Alternately, short life-cycle items will require larger one-time buys to support the expected system life-cycle.

- *Modularization*: The primary benefit of this second-order parameter is the ability to rapidly replace items with no impact to any other part of the system. This is especially appreciated by the maintenance personnel, as well as the engineer who may need to find a replacement unit for continued system life support or upgrades.
- *Guaranteed Price*: A guaranteed price, such as catalog pricing for COTS or agreements with the vendor provide the system integrator with control of some of his costs. It is also easier to estimate profits with such pricing.
- *Manufacturing Life-Span*: This parameter is an evaluation of the duration of the manufacturing run for the particular unit under study. Longer manufacturing life-span equates to less disruption in maintaining stock during the system manufacture/integration. It also reduces the probability of performing a life-time buy of spares when the contract is let, and allows the spreading of such costs over a longer period of time. This maintains fairly constant contract costs, eliminating spikes caused by such buys and allowing the Government customer to budget costs more easily.
- *Safety*: The safety parameter was rated fairly low, not out of any desire to ignore the well-being of the worker, but as an acknowledgment that manufacturers rarely make intentionally unsafe products. The current judicial system insures that is difficult to do. However, the cognizant design engineer should still ascertain that the product under consideration exhibits no unsafe conditions, in case the manufacturer overlooked some condition or the unit will be used in a method or location unanticipated by the OEM which could lead to a hazardous condition.
- *Drawing Package*: Surprisingly, a drawing package was rated lower than anticipated. Although considered important by some personnel surveyed, the importance depended on the maintenance concept suggested. Organizational maintenance relied less heavily on a drawing package than intermediate maintenance, while depot maintenance needed a drawing package to accomplish their task. A change in the maintenance concept could increase the weight of this parameter in its category.

- *Performance in Excess of Specifications*: Lowest on the list of second-order parameters was any performance in excess of specifications. When questioned, the survey respondents suggested that any performance above what the customer wanted was serendipity. This measure does not weigh heavily into the Unit Data category except as a discriminator between two otherwise equally matched units.

Table 3 provides a listing of the second-order parameters and shows the survey results as originally performed. Since the survey, the categories were re-evaluated and two were moved to more appropriate first-order parameters. Reliability is actually a measure of effectiveness and was therefor moved to that evaluation category. Although the parameter "Control of Changes" at first seemed tied to the unit selected, re-examination placed this measure in the "Supplier Rating" category. Every attempt was made to maintain the relative weight of these criteria as assigned through the survey results.

Table 3
Unit Data: Second-Order Parameter Weighting

Unit Data	Ranking	Survey	Weight
Standardized Components/Interfaces	1	2	9
Safety	7	9	3
Modularization	4	5	6
Human Factors	2	3	8
Guaranteed Price	5	7	5
Reliability	n/a*	1	-
Control of Changes	n/a*	6	-
Manufacturing Life-Span	6	8	4
Performance in Excess of Specs.	9	11	1
Projected Life-cycle	3	4	7
Drawing Package	8	10	2

*Moved since survey. Now evaluated under effectiveness and supplier data.

System Support

The first-order parameter "System Support" is a measure of the support provided by the OEM for their products. As Figure 9 illustrates, this evaluation category addresses the supplier provided services and their service abilities. This contrasts with the supplier rating discussed later which provides a snap-shot of the suppliers current condition. The second-order parameters for System Support read like a list of maintenance activity concerns. Although this may not seem important to the engineer designing a system and selecting its components, an average effective system life of 20 years with the U.S. Government makes maintenance a very big concern. Second-order parameters for the "System Support" parameter include, in order of weighting:

- *Support Requirements*: This parameter is a measure of the inventory of spares required to support the fielded population of units. Since it is dependent on the failure rate of the units, and a finite cost figure can be attributed to the required inventory, this parameter is part of the life-cycle cost evaluation. Spare quantity determination can be made using the methodology outlined in Appendix B.
- *Quality Rate*: The quality rate in the case of system support is a measure of the OEM's ability to repair or replace failed units. This is also known as a "first-time repair rate." Since sparing calculations rely on a known turn-around time and the quality rate is assumed to be 100%, any deviations from this measure must be accounted for. Changes in turn-around time can drastically affect sparing levels and inventory costs, especially considering the high spare availability requirements usually imposed on Government programs.
- *Turnaround Time*: From the discussion above, it is apparent that turnaround time also weighs heavily in the evaluation of system support. The faster turnaround time, combined with a high quality rate, results in lower required inventories of spares and therefor a reduced cost for sparing.
- *Response Time*: The time it takes a vendor to respond to a problem or failure has a direct bearing on the system availability. The response can be a resolution to a call from organizational maintenance personnel for telephone assistance, or it can be a response to provide organizational maintenance, if

so contracted. The response time definition will be determined by the maintenance concept derived in the conceptual design phase. For example, if a 7 day/week, 24 hour/day Government program requires a 4-hour average restoration time and the organizational maintenance provided by the OEM only guarantees a 2-hour response from 0800-1700, Monday through Friday with a 2.5 hour MTTR, then the response time is inadequate.

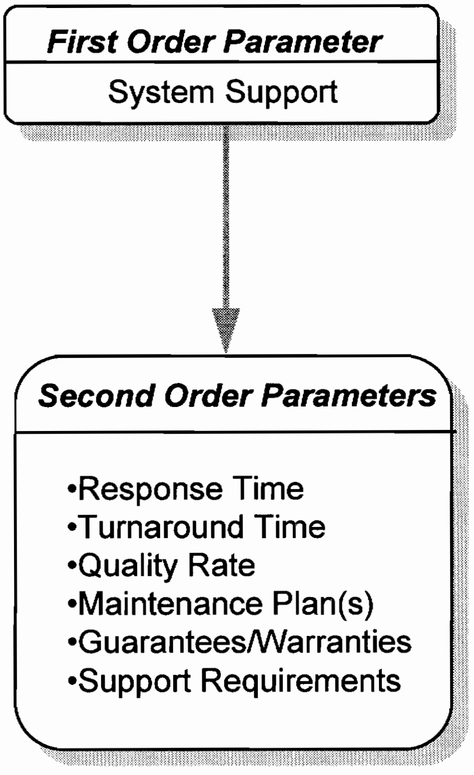


Figure 9
Evaluation Category: System Support

- *Maintenance Plan*: The adequacy of the maintenance plans provided by the OEM or their willingness to cooperate with the system developer to provide the best maintenance is also important. If the only maintenance plan offered by an OEM under consideration, or even by the supplier of the custom equipment, is such that the maintenance cost of the system is unreasonable or prohibitively expensive, then another solution will probably be considered instead. If, on the other hand, the maintenance plan(s) offered are many and varied, to the point of being tailored to the Government customer's specific requirements, while the cost of each plan is low due to shared resources or other reasons, then the maintenance of the selected item should not present any obstacles.

- *Guarantees/Warranties*: Last of the secondary parameters for System Support is the OEM provided guarantees and warranties. Such plans provide a degree of protection against the infant mortality evidenced in the system life-cycle and illustrated in the "bathtub curve" of Figure 5 on page 16. However, in many cases the warranties are expired before the system reaches the customer, or the guaranties are voided through minor modifications to the units. Therefor, this parameter is rated last in the weighting criteria.

Table 4 below illustrates the weighting criteria for the second-order parameters of the evaluation category "System Support." The vendors under consideration are ranked in each category, and the weighting factor applied to the inverse of their relative standing. If a vendor were ranked first of ten competitors in the area of Guarantees/Warranties, his point total would be the weight (1) times 10 for a total of 10 points. Likewise, if the same vendor was ranked fourth of ten in Turnaround Time, his point total in that category would equal the weight (4) times seven for a total of 28 points.

Table 4
System Support: Second-Order Parameter Weighting

System Support	Ranking	Weight
Support Requirements	1	6
Quality Rate	2	5
Turnaround Time	3	4
Response Time	4	3
Maintenance Plan	5	2
Guarantees/Warranties	6	1

Supplier Rating

The first level parameter of "Supplier Rating" provides a discriminator for the selection of the better quality vendor. Figure 10 illustrates the various areas of evaluation of the supplier. These second-order parameters are primarily concerned with general information about the vendor, rather than specific information about the individual product under evaluation. Note that the criteria "Quality" is different from the "Quality Rate" used as a second-order parameter in the "System Support" category.

- *Current Financial Condition*: This ranking criteria concerns the financial ability of the manufacturer of the solution under examination to be around for a number of years. A sound financial condition with projected continued good performance is obviously more desirable than a manufacturer who may not be around next following week. Even if a product line is discontinued a short time into the life-cycle of the program which uses that product, the continued existence of the company increases the chances of a limited re-run of the product or a similar substitute at a later date. For Government programs with a life of 20 years, longevity and sound financial condition is a definite asset. The current financial condition of a company can be measured through either first-party disclosure from the vendor, or from a third-party source such a Dun and Bradstreet rating or stock histories. Financial condition is a direct result of the supplier's ability to manage resources and a forecast of their longevity.
- *Product Experience*: A supplier's experience in the technology for which a solution is required is an important measure of that supplier's qualification and ability to provide the solution. There are few, if any substitutes for experience and lessons learned in producing an item, whether software or hardware. Previous experience, coupled with success, is a good indication that the next product or generation of product will likely enjoy a similar success. Note that it is not a guarantee, just a good indication.

  The perspective supplier's track record can be gleaned from a number of sources. Again, the best source of such information is Dun & Bradstreet.

Product experience is weighted against the supplier's ranking, since this experience relates directly to the history of the company.

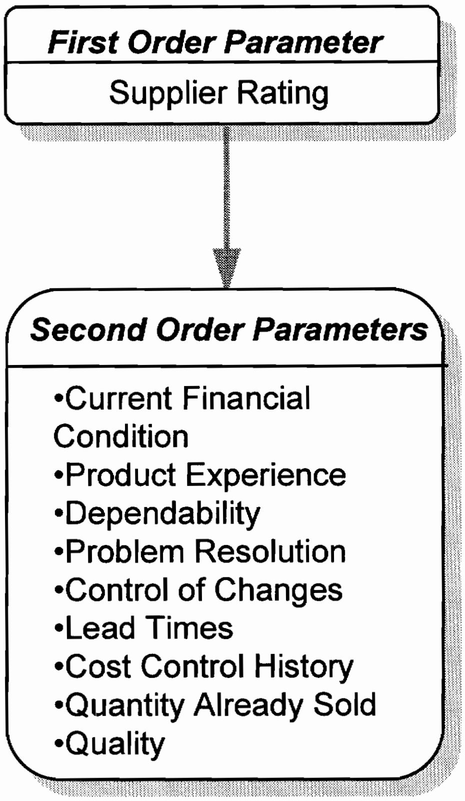


Figure 10
Evaluation Category: Supplier Rating

- *.Dependability*: The dependability of the supplier is another of the more important measures. Especially in a time-critical situation, or when relying heavily on the supplier's data, the dependability of that supplier is paramount. An evaluation of dependability can only be made from past observation, previous association, or references from a reliable third party. The weighting for dependability was assigned to the supplier data category since this measure was a direct result of the vendor's historical actions.
- *Problem Resolution*: The ability of the supplier to resolve problems is an asset in resolving unforeseen performance difficulties or operational discrepancies after the delivery of a sub-assembly by the supplier. Problem

resolution was weighted against the supplier performance since it was a direct reflection of the supplier's engineering abilities.

- *Control of Changes*: Closely related to problem resolution is the control of changes. If the resolution of a problem is a modification to the product, then the handling and control of that modification is also important. The OEM must have the ability to control the documentation and issuance of changes.
- *Lead Time*: Lead time for the delivery of a contracted solution is important in the establishment of the manufacturing schedule, the time required to deliver the finished system, and in the case of rapidly changing technology, the time to market with a still-viable system solution. The lead time weighting criteria was assessed directly against the supplier's ranking, since the supplier directly controls the lead time.
- *Cost Control History*: Another important criteria, used for accurate estimation of maintenance costs, is the cost control history of the OEM. If a product price increases faster than the cost of money, the original estimates of life-cycle cost may be invalid. The OEM's historical ability to control the price of their product should be a good indicator of their future performance in this area.
- *Quantity Already Sold*: The quantity of a product sold or booked provides a basis for evaluating the success of the product and forecasting the maintenance competition for the item under evaluation. Current users can be contacted for actual performance data, while a large population base is also an indicator of good competition in the maintenance arena. With a large population base, economies of scale can be realized to spread and reduce the cost of maintenance.
- *Quality*: Surprisingly, quality was rated very low by the surveyed group. However, other factors in other categories are already measures of quality and compensate for this low rating in other areas. Note that this quality rating is different from that discussed in the first-order parameter "System Support." There, quality rating was likened to a first-time repair rate. This quality criteria is an overall rating which addresses all of the factors about a supplier which cannot be captured in any specific criteria.

Table 5 below shows the results of the survey performed, the final ranking assigned to each criterion, and the weight assessed to that category. As in previous second-order parameter rating, the vendors under evaluation are ranked according to their merits in any one category. For instance, if the pool of vendors whose solutions are being evaluated totals 10, then they are ranked in order from first to tenth, and the weighting factor applied to the inverse of their relative standing. If a vendor were ranked first of ten competitors in the area of Current Financial Condition, his point total would be the weight (4) times 10 for a total of 40 points. Likewise, if the same vendor were ranked fourth of ten in Problem Resolution, his point total in that category would equal the weight (3) times seven for a total of 21 points. A filter can be applied to criteria that may have sources of error or inaccuracy. This type of filter is discussed in the following section.

Table 5
Supplier Rating: Second-Order Parameter Weighting

Supplier Rating	Ranking	Survey	Weight
Current Financial Condition	5	5	4
Product Experience	6	6	3
Dependability	8	8	1
Problem Resolution	3	3	6
Lead Times	1	1	8
Cost Control History	2	2	7
Quantity Already Sold	2	2	7
Quality	7	7	2
Control of Changes	4*	4	5

*Moved since survey from unit data.

Data Accuracy Filter

At the bottom of the evaluation list, a criterion must be applied against certain data elements to weigh the validity of the data supplied. Generally, data about a COTS or custom solution is available through three sources:

1. Data provided by the supplier of the solution
2. Data provided by the supplier, backed by performance data
3. Data provided by the supplier and verified by a reliable second source

In the same category as item 3 is data provided by a reliable second source or observed by the requester of the data. For example, past performance history about a supplier may be available from someone who has utilized the services of that supplier previously.

Data provided by the supplier (category 1), with no other corroborating evidence, cannot be considered reliable data. Although most suppliers would not intentionally misrepresent the truth, their own perception of their goods and services are different from the user's perceptions. After some discussion with colleagues involved in purchasing supplies and procuring contracts, a weighting accuracy of 50% was assigned to this category.

Data provided by the supplier, backed by performance history (category 2) with no other corroborating evidence, was assigned an accuracy rating of 75%. This again reflects that all the data provided is from the supplier, and their own perceptions are ingrained in the supporting data as well. It would be a simple matter, however, to verify the provided performance data and push the validity of the data into category 3

Data provided by the supplier and verified by a reliable second source (category 3) is considered 100% accurate. As in any evaluation, there are many shades of gray in these categories. The percentages used are a guideline, and can be modified during the collection process if the evaluator feels that the provided data is more or less accurate.

Data accuracy provides a weighting filter, and the percentage assigned against the accuracy of the data is used as a multiplier against the weight of the evaluation elements in Table 6.

In the first-order parameter of Effectiveness, the application of the filter is not quite as straight-forward, but can still be applied. For example, if the MTBF

Table 6
Weighting Filters

First-Order Parameters	*Second-Order Parameters*	*Data Elements*	*Adjusted Weight*		
			Cat 1	*Cat 2*	*Cat 3*
System Support	Quality Rate	Quality Rate	2.5	3.75	5
Supplier Rating	Problem Resolution	Time to Resolve	3.0	4.50	6
	Control of Changes	Control of Changes	2.5	3.75	5
	Product Experience	Years	1.5	2.25	3
	Dependability	Dependability	.5	.75	1

is provided by the manufacturer, the weighting filter would be applied against it, depending on the data source, thus affecting the availability. If an MTBF of 5000 hours were supplied by the manufacturer with no supporting data (Category 1), the MTBF would be reduced by half to 2500 hours. If an MTTR of 1 hour was supplied with no supporting data, it would be increased to 1.5 hours. Again, this weighting can be adjusted, as long as it is applied equally to all units/solutions under evaluation.

Case Study

To provide an example of the usage of the developed checklist to the evaluation process, a case study is presented here using the general checklist developed in this project. The case study assumes for simplicity that three options are available to satisfy the requirements and specifications allocated to a sub-assembly herein referred to as “LRU”. These three options are COTS solutions provided by vendor “A” or “B”, or a custom-designed unit built in-house (vendor X). The weighting criteria have already been developed and will be used as ranked in Table 1 on pages 32 and 33. All evaluation data presented in Table 7 are shown on a per unit basis. This data was created one vendor at a time with a range of allowable values from which to select. Where a rank was used, each second-order parameter was evaluated separately to reduce bias.

Table 7
Case Study: Checklist Data Elements

First-Order Parameters	A	A (rank)	B	B (rank)	X	X
Life-Cycle Cost	**$98,200**	**1**	**$103,400**	**2**	**$107,000**	**3**
Research & Development	n/a	1	n/a	1	$10,000	2
Materials	$26,000	2	$37,000	3	$14,000	1
Production	n/a	1	n/a	1	$7,000	2
Operations (projected life)	$40,000	3	$25,000	1	$31,000	2
Maintenance	$31,200	1	$40,400	2	$44,000	3
Disposal	$1,000	1	$1,000	1	$1,000	1
Effectiveness						
Availability	.95	3	.96	2	.98	1
Preventive Maintenance	12 hrs	2	4 hrs	1	4 hrs	1
Calibration	n/a		n/a		n/a	
Maintainability	see discussion, page 38					
Unit Data						
Standard Components, I/F	95%	2	95%	2	all	1
Human Factors	rank	1	rank	3	rank	2
Projected Life-Cycle	20 yrs	1	15 yrs	3	20 yrs	1
Modularization	rank	2	rank	2	rank	1
Guaranteed Price	rank	1	rank	2	rank	2
Manufacturing Life-span	1 yr.	1	6 mo	3	1.5 yr.	1
Safety	rank	1	rank	3	rank	2
Drawing Package	no	2	no	2	yes	1
Excess Performance	rank	1	rank	2	rank	3
System Support						
Support Requirements	medium	2	low	1	high	3
Quality Rate	rank	1	rank	3	rank	2
Turnaround Time	7 days	2	10 days	3	2 days	1
Response Time	8 hour	2	24 hour	3	4-hour	1
Maintenance Plan	full only	3	multi	1	full/base	2
Guarantees/Warranties	90 day	2	30 day	3	6 mo.	1

Table 7 (continued)
Case Study: Checklist Data Elements

First-Order Parameters	A	A (rank)	B	B (rank)	X	X (rank)
Supplier Rating						
Lead Times	2 weeks	1	2 weeks	1	4 weeks	2
Quantity Already Sold	none	2	400	1	none	2
Cost Control History	rank	1	rank	1	rank	1
Problem Resolution	rank	2	rank	1	rank	2
Control of Changes	rank	2	rank	3	rank	1
Current Financial	rank	1	rank	2	rank	2
Product Experience	2 years	3	5 years	1	3 years	2
Quality	rank	1	rank	2	rank	1
Dependability	rank	1	rank	3	rank	2

The data presented in Table 7 is based on some general assumptions. First, all data whose cells have the value "rank" entered are relative measures based on research into the vendor. The resulting relative ranking in that category is subjective, based on the results of the research. For example, under Supplier Rating, in the area of Quality, vendors A and X were ranked as equal to each other, but better than vendor B. Such a ranking may be based on reject rate, previous customers' experience with the vendor's product, and so on.

Using weighting filters such as those discussed in the previous section, the Effectiveness data is adjusted based on the source of the data. Table 8 shows the application of such a filter in this category. Some thought must be put into the application of these general weighting filter numbers. In the case of the availability numbers, it would be unrealistic to multiply the actual supplied effectiveness number by the penalty as this would result in an artificially low availability number. Instead, the factor is applied against the unavailability number (1 - availability). The resulting new unavailability number is then used to calculate the adjusted availability.

Table 8
Weighting Filters Applied to Select Effectiveness Measures

	Availability	Preventive Maintenance
Vendor A	.95	12 hrs
Category of Data	1	1
Adjustment	.05/.5=.1	(12 hrs) x .5=6 hrs
Adjusted Measure	1-.1 = .90	12 hrs + 6 hrs = 18 hrs
Original Ranking	3	2
Revised Ranking	3	3
Vendor B	.96	4 hrs
Category of Data	3	2
Adjustment	none	(4hrs) x .25 = 1hr
Adjusted Measure	.96	4 hrs + 1 hr = 5hrs
Original Ranking	2	1
Revised Ranking	2	1
Vendor X	.98	4 hrs
Category of Data	2	1
Adjustment	.02/.75 = .027	(4 hrs) x .5 = 2 hr
Adjusted Measure	1 - .027 = .973	4 hrs + 2 hr = 6 hrs
Original Ranking	1	1

The ranking of vendors A, B, and X is then inverted and multiplied by the weight as outlined on page 31. The first column for each vendor strictly follows the format specified at the top of Table 9, where the first number in the equation is the inverse of the ranking and the second number is the weight given to the second-order parameter as specified in Table 1. This weight is adjusted for certain parameters based on the source of data as shown in Table 6. Note that the category or source of data may be completely different within the each vendor. This is merely a reflection of the completeness of the data supplied by the vendor for that data point and the evaluators ability to verify the supplied data. Table 9 shows the math and the resulting total points for each second and first-order parameter, as well as a final ranking for each parameter.

Table 9
Application of Second-Order Parameter Weighting

Format of calculations for columns A, B, and X:
(Inverse ranking from Table 7) x (Weight from Table 1 with filters from Table 6 applied)

Second-Order Parameters (for Unit Data)	*A*	*A Total*	*B*	*B Total*	*X*	*X Total*
Standard Components, I/F	2 x 9	18	2 x 9	18	3 x 9	27
Human Factors	3 x 8	24	1 x 8	8	2 x 8	16
Projected Life-Cycle	3 x 7	21	2 x 7	14	3 x 7	21
Modularization	2 x 6	12	2 x 6	12	3 x 6	18
Guaranteed Price	3 x 5	15	2 x 5	10	2 x 5	10
Manufacturing Life-span	2 x 4	8	1 x 4	4	3 x 4	12
Safety	3 x 3	3	1 x 3	3	2 x 3	6
Drawing Package	1 x 2	2	1 x 2	2	3 x 2	6
Excess Performance	3 x 1	3	2 x 1	2	1 x 1	1
Total Points		**106**		**73**		**117**
Second-Order Parameters	*(Cat 2 Data)*		*(Cat 3 Data)*		*(Cat 3 Data)*	
(for System Support)	*A*	*A Total*	*B*	*B Total*	*X*	*X Total*
Support Requirements	2 x 6	12	3 x 6	18	1 x 6	6
Quality Rate	3 x 3.75	11.25	1 x 5	5	2 x 5	10
Turnaround Time	2 x 4	8	1 x 4	4	3 x 4	12
Response Time	2 x 3	6	1 x 3	3	3 x 3	9
Maintenance Plan	1 x 2	2	3 x 2	6	2 x 2	4
Guarantees/Warranties	2 x 1	2	1 x 1	1	3 x 1	3
Total		**41.25**		**37**		**44**
Second-Order Parameters	*(Cat 2 Data)*		*(Cat 3 Data)*		*(Cat 2 & 3 Data)*	
(for Supplier Rating)	*A*	*A Total*	*B*	*B Total*	*X*	*X Total*
Lead Times	3 x 8	24	3 x 8	18	2 x 8	16
Quantity Already Sold	2 x 7	14	3 x 7	21	2 x 7	14
Cost Control History	3 x 7	21	3 x 7	21	3 x 7	21
Problem Resolution	2 x 4.50	9	3 x 6	18	2 x 4.50	9
Control of Changes	2 x 3.75	7.5	1 x 5	5	3 x 3.75	11.25

Table 9 (cont.)
Application of Second-Order Parameter Weighting

Second-Order (for Supplier Rating)	*(Cat 2 Data) A*	*A Total*	*(Cat 3 Data) B*	*B Total*	*(Cat 2 & 3 Data) X*	*X Total*
Current Financial	3 x 4	12	2 x 4	8	2 x 4	8
Product Experience	1 x 2.25	2.25	3 x 3	9	2 x 3	6
Quality	3 x 2	6	2 x 2	4	3 x 2	6
Dependability	3 x .75	2.25	1 x 1	1	2 x .75	1.50
Total		**98**		**105**		**92.75**

Table 10 below is the next step of the analysis in which the rank of the first-order parameters is determined based on the evaluation of the second-order parameters. Note in Table 10 that the application of the weighting filter in the previous step was responsible for dropping the rank of Vendor "A" from first to second place in the Supplier Rating first-order parameter, and from first to second in the System Support first-order parameter. The filters also moved Vendor "X" from second to third place in the Supplier Rating.

Table 10
Application of First-Order Parameter Weighting

First-Order Parameters	*A*		*B*		*X*	
	Total	*Rank*	*Total*	*Rank*	*Total*	*Rank*
Life-Cycle Cost (Table 7)	*$98,200*	**1**	*$107,40*	**2**	*$107,000*	**3**
Effectiveness (Table 7 & 8)	*.899*	**3**	*.959*	**2**	*.979*	**1**
Unit Data	*106*	**2**	*73*	**3**	*117*	**1**
System Support	*41.25*	**2**	*37*	**3**	*44*	**1**
Supplier Rating	*98*	**2**	*105*	**1**	*92.75*	**3**

The final rankings based on the supplied data and the application of the weighting criteria as outlined in this study are shown in Table 11. Note that Vendor "X", the custom-designed unit, was first. Without the application of the weighting filters however, Vendor "A" with a COTS solution would have been the provider of choice. This case study emphasized again the importance of determining weighting criteria in the conceptual design phase. With the weight of each parameter and the weighting filters already determined, it was difficult to skew the numbers to bias the checklist in favor of the desired outcome. Note that in this case study, certain factors which may have favored COTS solutions were not incorporated, such as short lead times or industry standard devices. These requirements would have certainly changed weighting criteria and put much pressure on the provider of the custom solution to develop and test a product in an extremely short time frame, thereby possibly affecting the performance adversely.

Table 11
Final Ranking of Vendors

First-Order Parameters	*A*	*A (rank)*	*B*	*B (rank)*	*X*	*X (rank)*
Final Ranking		**2**		**3**		**1**
Life-Cycle Cost	3 x 4.5	13.5	2 x 4.5	9	1 x 4.5	4.5
Effectiveness	1 x 4	4	2 x 4	8	3 x 4	12
Unit Data	2 x 4	8	1 x 4	4	3 x 4	12
System Support	2 x 3	6	1 x 3	3	3 x 3	9
Supplier Rating	2 x 2	4	3 x 2	6	1 x 2	2
Total		**35.5**		**30**		**39.5**

Conclusion

A simple, checklist for the evaluation of COTS equipment in Government programs is not an easily determined tool. As in any other system engineering project, the entire system must be considered in creating the proper tool. A weighting criterion that may work on one program may not provide a true evaluation on another. One requirement from the customer can change the entire nature of the selection process. If, for example, the lead-time for the proposed system is too short, a custom solution may not be viable. Standardized interfaces may become paramount in the evaluation, requiring an even heavier weight to differentiate it from the next suggested criteria, human factors. As stated before, to successfully select the best solution using the available information, the rating criteria must be established during the conceptual design phase of the life-cycle. Corporate culture, concepts, requirements or other conditions may change the order or the weighting of this list. The second-order parameters and filters presented in the checklist in Table 1 must be ranked within their own first-order parameter, and those first-order parameters ranked relative to each other by a proposal manager or program manager with an understanding of system and customer requirements. Additional criteria can be added if the manager feels that they are not already adequately represented, or require additional representation. In no case should the actual evaluator be allowed to modify the weighting criteria, especially after the evaluation has begun. The idea is to establish the weighting at the conceptual phase based on the program requirements, and to allow the evaluator to accumulate data, apply the weighting, and allow the resulting scores to make the final selection.

The process presented in this study is not the only tool available for the selection of COTS or custom solutions to Government programs, however, it is an attempt at simplifying the process. With this checklist, the design or project engineer can delegate the task of collecting raw data, and once provided with the data, make a rapid decision on the correct solution to best meet the overall system requirements.

Further Studies

Upon the completion of this study, I realized that a number of areas had only raised other questions, or were out of the scope of what this study was intended to accomplish. One area that requires further investigation is the selection of COTS software. Although a number of areas will be evaluated in the same fashion as hardware, different parameters may need to be examined for an accurate appraisal. Weighting criteria for software selection are also different, as is the order of those criteria. The first-order parameters would be weighted in a different order, thereby altering the final selection criteria. Supplier data would weigh more in the final analysis because of the probable need for assistance in problem solving and therefore a heavier reliance on the supplier's continued existence and ability to solve problems. Life-cycle cost would be more difficult to evaluate because of the difficulty in predicting "failures" and the cost of the man-hours to create work-arounds or "bug fixes". Rather than dwell on these differences, this area is open for further study.

Another area which would benefit from more research is a more analytical approach to the weighting of the various criteria. The survey used here is only a small sample of one company's way of doing business. Representative statistical samples by industry or discipline would provide a better basis for the final weighting of the parameters in the checklist. A more rigorous approach might also resolve the issue of the ranking assigned to the first-order parameter "Unit Data". Although ranked first by the survey performed, those who ranked it low or last were the more experienced or senior personnel. All had the same argument, saying that a unit which did not at least marginally meet the specifications would not be evaluated, unless there was nothing available which met the requirements. Considering this perspective, they felt that unit performance was more of a discriminator rather than the weightiest criteria. I have already taken the liberty of changing the relative ranking of the first-order parameters, but this criterion in particular could use more research.

Another level of detail below the second-order parameters also requires further investigation. Step 5 of figure 4 is to determine the elements of the second-order parameters. These elements should result in a detailed list of questions to ask potential vendors in order to acquire the data needed to complete the evaluations. I have left the determination of these questions for a further study also.

Finally, the whole process would benefit immensely from the use of a computer program or mathematical model to enter the data into. Something as simple as a spreadsheet could be used, or a more complex computer program using prompts and asking as yet unanswered questions for each vendor. Such a tool would also be useful for establishing future checklists as well by providing a reference database of past evaluations.

APPENDIX A

The following survey was provided to a wide cross-section of personnel involved in a proposal effort for a large Government contract which had a requirement for the extensive use of COTS. Personnel backgrounds included program managers; design, system, and software engineers; facilities designers; contracts, operations and maintenance personnel. Their inputs were used as a basis for the weighting criteria established for the checklist in this study. Charts and graphs have been attached after the survey to provide a break-out of the scoring.

Criteria Weighting Survey

Supplier Data - information about the prospective supplier of the assembly or sub-assembly under consideration. Supplier can also be your own company if you are designing the item yourself. If you feel that more than one of these criteria is about the same in term of importance, its O.K. to rank them the same. For example, if you feel that quantity sold and dependability rank 3rd on the list, its O.K. to give them both a 3 and keep going. By the way, this data has been deliberately scrambled from my own ranking so as not to influence your input. These items will result in a vendor ranking factor to apply against the data provided from the vendor prior to the selection of a COTS or custom designed unit.

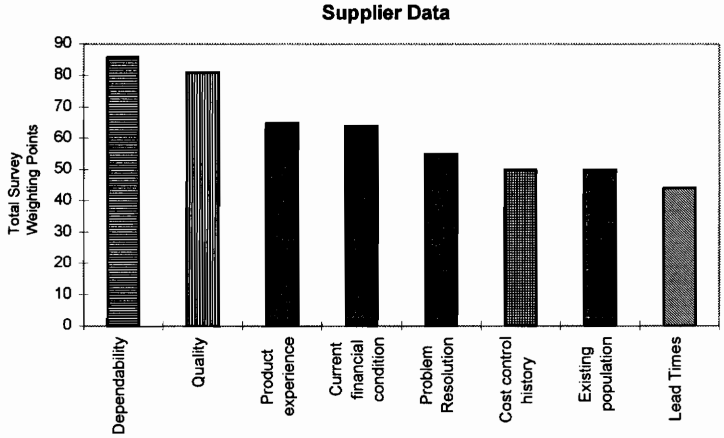
______ - Current financial condition
______ - Product experience
______ - Dependability
______ - Problem Resolution
______ - Lead times
______ - Cost control history
______ - Quantity already sold
______ - Quality

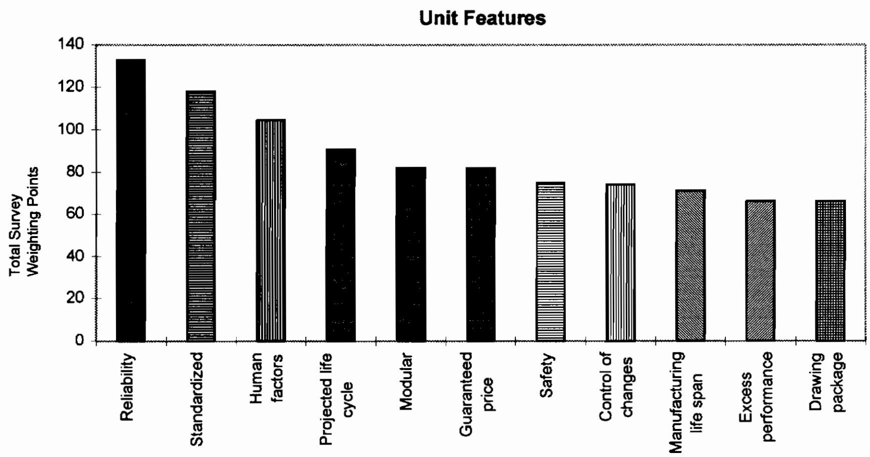
The following list ranks the individual features of the items being evaluated, both COTS and the custom solution. Please rank these in the same fashion as the above group. Same criteria apply if you feel more than one should receive the same weight.

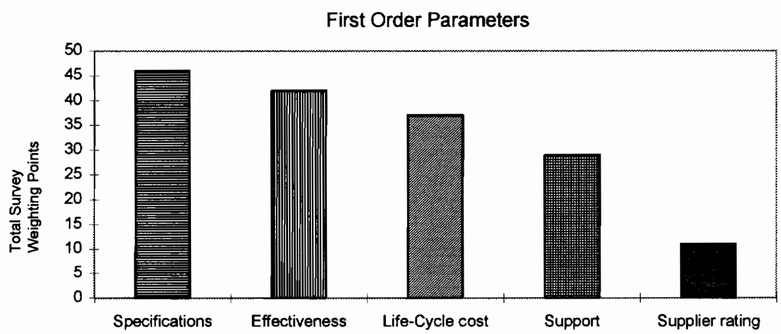
______ - standardized components and interfaces (compatibility with the rest of the system)
______ - safety (may not apply to all items, but rank anyway)
______ - modularization
______ - human factors (control panel, displays, etc.)
______ - Guaranteed price (generally will apply to COTS)*
______ - Reliability
______ - Control of changes*
______ - Manufacturing life-span (length of production run)
______ - Performance in excess of specifications
______ - Projected life-cycle
______ - Drawing package: includes drawings, material lists, parts lists, operating procedures, maintenance instructions, overhaul instructions, illustrated parts breakdown (IPB), calibration procedures, configuration management data, documentation describing modifications and changes.

Please rate the following four major categories. These are the categories that will be used for the final evaluation of the COTS alternative versus the custom.

______ - Supplier rating
______ - System performance (specifications)
______ - Life-Cycle cost (design or buy through disposal)
______ - System support (maintenance plans, OEM logistics)
______ - Effectiveness (availability, reliability, maintainability)







The three charts above plot the results of the survey in this Appendix. The measure on the y-axis indicates the total points from all surveys for the parameters indicated on the x-axis.

APPENDIX B

The equation noted below is used for the calculation of spare requirements using the Poisson distribution. In this calculation, s equals the desired number of spares to satisfy the availability requirements. Let

$$P = \sum_{n=0}^{n=s} \left[\frac{(R)\left[-(\ln R)^{n}\right]}{n!} \right]$$

where

P = probability of having a spare of a particular item available when required

s = number of spare parts carried in stock

R = composite reliability (probability of survival)

K = quantity of parts used of a particular type

ln R = natural logarithm of R

Solving for s results in the recommended spares quantity.[16]

[16] Benjamin S. Blanchard and Wolter. J. Fabrycky, *Systems Engineering and Analysis*, 2nd ed. (Englewood Cliffs, N.J.: Prentice Hall, 1990), pp. 476-480.

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