1.0 INTRODUCTION TO OPERATIONAL AVAILABILITY (A_o)

1.1 Introduction

This handbook presents a practical overview of the concept of operational availability and several supportability measures and their use in different phases of a system's[1] life cycle. It is hoped that better understanding of the metrics involved and their derivation will provide insight to program sponsors and acquisition managers as they develop and manage their programs.

The operational availability (A_o) of systems is key to an organization's ability to be successful while minimizing cost. Our military forces cannot accomplish their missions without effective systems and proper support. Military systems must be designed with both effectiveness and supportability in mind. The acquisition process must be cost-effective and provide the necessary infrastructure support to achieve readiness requirements. Supportability considerations must be integral to nearly all trade-off decisions.

Project Managers must be able to assess system performance readiness metrics during the acquisition process, prior to initial operational capability (IOC), and throughout the deployment cycle, providing feedback critical to ensuring that the user can affordably support the system. This handbook is intended to be a practical guide; however although several useful equations are provided, it is not intended to be an exhaustive mathematical or engineering treatise.

This handbook is based on one initially developed, by the Department of the Navy in the mid 1980s to address the combined consideration of A_o and cost in all levels of systems acquisition and design related decision-making. This handbook generalizes and broadens the application of the concepts and incorporates the tenets of acquisition reform, organizational re-alignment, and provides additional clarity to the interaction between A_o and cost of ownership.

Common use of terms is essential in this kind of handbook. The DoD and defense industry have defined material readiness as one of two prime Figures Of Merit (FOM) to be used for acquisition program decision support. The first FOM is the equivalent of material readiness or hardware availability. The second FOM is Total Ownership Cost (TOC) of the system or equipment under consideration. TOC for purposes of this handbook is equivalent to cost of ownership. Although many of the terms and initiatives discussed herein are unique to the military, the basic concepts are also applicable to industrial and commercial products.

1.2 Understanding A_o

The next few paragraphs provide insight to availability and several other important metrics; a more detailed treatise follows in later sections.

Availability can be generally defined as the probability that a system will be ready to perform its mission or function under stated conditions when called upon to do so at a random time. It is a

[1] For convenience, the term "systems" is used in this handbook to include military weapons systems, industrial systems, and commercial products.

term associated with systems that can be repaired or have other maintenance performed. As such, availability is a function of how often the system fails (a function of reliability) and how long it takes to restore the system to an operational condition after a failure occurs (a function of maintenance and support). For systems for which no maintenance is possible or practical (not even inspections or servicing), availability is equal to the system reliability. Reliability can be defined as the probability that a system will perform its function(s) as required when used under stated conditions for a given interval of time without failure.

When the general definition of availability is modified to assume ideal support (i.e., unlimited spares, no delays, etc.) and only design- or manufacturing-related failures are considered, we have inherent availability (A_i). A_i reflects the level of reliability and maintainability (R&M) achieved in the design and realized through the manufacturing, assembly, and, in some cases, installation processes.

When a realistic support environment is considered and all maintenance actions, even those not required as a result of design- or manufacturing-related failures, are considered, we have operational availability (A_o). A_o is a function of reliability, maintainability, and supportability. Every effort should be made to explicitly consider each element of A_o in early development and throughout the system's life cycle. As you use this handbook, keep two important things in mind; first and foremost, operational availability is a key element in determining system readiness[2] and a supportability goal. Second, the system design does not solely determine A_o, but dictates a maximum level of availability based only on the designed-in levels of R&M. Reliability is often expressed in terms of the Mean Time Between Failure (MTBF) and maintainability in terms of Mean Time To Repair (MTTR).

Figure 1.2-1 helps us to better understand the difference between A_i and A_o. Note that no matter how it is measured, availability can never be more than 100% (1.0) or less than 0.

Measure	Equation	Reflects
Inherent Availability	$A_i = \frac{MTBF}{MTBF + MTTR}$	The level of R&M achieved in design and the fidelity of the manufacturing processes.
Operational Availability	$A_o = \frac{MTBM}{MTBM + MDT}$	The level of R&M achieved in design, the fidelity of the manufacturing processes, maintenance policy, in-theater assets, order/ship times, etc.
Where: MTBF is the mean time between "hard" failures MTTR is the mean time to repair as a function of design MTBM is the mean time between maintenance, all corrective and preventive maintenance MDT is the mean downtime, which includes the actual time to perform maintenance and accounts for any delays in getting the needed personnel or parts, number of spares on hand, etc.		

Figure 1.2-1. Logistics Impact on Operational Availability

Availability is often mistakenly equated to reliability. Reliability is a function based on the actual physical components in the design and is generally defined as the probability that an item

[2] Readiness is a broader term that accounts for the number and level of training of operating personnel; command, control, and communications, mobility; planning; strategy and tactics; and other factors.

will not fail to perform its function(s) when used under stated conditions over a defined time period. When the times to (for non-repairable items) or times between failures are exponentially distributed, the equation for reliability is:

$$R(t) = e^{-\lambda}$$

where:

e is the natural logarithm
λ (lambda) is the failure rate
t is the time period for which the reliability is calculated

Reliability, being a probability, can take on any value between 0 and 1. Often reliability is expressed as MTBF. For the exponential distribution of failure times, the MTBF is the inverse of the failure rate (λ). For example, if a system failure rate is 5 failures per thousand hours, it follows that the MTBF is equal to 200 hours.

Reliability is an important factor in availability. Another factor of availability is maintainability. Maintainability is often defined as "the measure of the ability of an item to be retained in or restored to a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair." Other reference documents define maintainability in slightly different ways. In an important way, many of these definitions are incomplete. Maintainability is concerned with the relative ease and economy of preventing failures (retaining an item in a specified condition) or correcting failures (restoring an item to a specified condition) through maintenance actions. So, good maintainability is not simply the ability to keep a product operating using prescribed procedures and resources. It is the ability to do so economically and efficiently.

Consolidating the ideas in the definitions found in various references and adding the idea of economy, yields the following definition:

> *Maintainability.* The relative ease and economy of time and resources with which an item can be retained in, or restored to, a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair. In this context, it is a function of design.

As stated in the last sentence of the definition, maintainability is a design parameter. Although other factors, such as highly trained people and a responsive supply system, can help keep downtime to an absolute minimum, it is the inherent maintainability that determines this minimum. Improving training or support cannot effectively compensate for the effect on availability of a poorly designed (in terms of maintainability) product. Designing the product to be reliable and maintainable is the best way to minimize the cost to support a product and maximize the availability of that product.

Maintainability is measured in many different ways, quantitatively and qualitatively. Table 1.2-1 summarizes a few of these measures.

Table 1.2-1. Measures of Maintainability

Measure	Comment
Mean Time to Repair (MTTR). Also called Mean Corrective Maintenance Time $(\overline{M}_{ct})$.	A composite value representing the arithmetic average of the maintenance cycle times for the individual maintenance actions for a system.
Mean Preventive Maintenance Time $(\overline{M}_{pt})$.	A composite value representing the arithmetic average of the maintenance cycle times for the individual preventive maintenance actions (periodic inspection, calibration, scheduled replacement, etc.) for a system.
Median Active Corrective Maintenance Time $(\tilde{M}_{ct})$.	That value of corrective maintenance time that divides all downtime values for corrective maintenance such that 50% are equal to or more than the median and 50% are equal to or less than the median.
Mean Downtime (MDT).	The mean or average time that a system is not operational due to repair or preventive maintenance. Includes logistics and administrative delays.

Design guides and analysis tools must be used rigorously to ensure a testable design. Not doing so leads to greater costs in the development of manufacturing and field tests, as well as in the development of test equipment. Tradeoffs must be made up front on the use of built-in-test (BIT) versus other means of fault detection and isolation. Further, the expected percentage of faults that can be detected and isolated to a specified or desired level of ambiguity must be determined as an important input to the logistics analysis process. The consequences of poor testability are higher manufacturing costs, higher support costs, and lower customer satisfaction.

Reliability and maintainability are often considered the foundation of availability. Both are primarily determined during design. Once the equipment is designed and built, reliability and maintainability can be modified only, with minor exceptions, by changing the physical design of the equipment.

However, operational availability is not just a function of design but also of maintenance policy, the logistics system, and other supportability factors. It can be improved by improving the design, improving the support, or both.

This handbook will provide detailed A_o applications, explanations, and rationale by acquisition phase. Users and program managers must understand how to contract for availability and how best to invest program funds to provide cost effective, available systems. This handbook was prepared to help program sponsors, program managers, product support agents, and others deal with this challenge. It will discuss in detail the overall process of developing and evaluating A_o thresholds during the systems acquisition process. Support concepts such as third party customer service and performance based support coupled with Commercial Off The Shelf (COTS) procurements will have a great impact on defining the A_o goals and support requirements including costs. The following key points are provided as a preview of the major issues that will be addressed:

- The Resource Sponsor, with assistance from the developing agency and others, must document A_o as a Key Performance Parameter (KPP) in requirements documents.
- To understand and effectively evaluate A_o and cost during the systems acquisition process, the resource sponsor and others must become familiar with the separate components of the A_o index. These are reliability, maintainability, and supportability.
- Every effort should be made to explicitly consider each element of the A_o metric throughout the system life cycle. The program team and the user must understand that major changes to or deviations from the user requirements or the designated operational scenario requirements may have an impact upon the observed A_o. In addition, if spares availability are reduced for any reason (budget or supply chain), the cannibalization rate will increase and the readiness, as observed by the user, will decrease.

1.3 Handbook Scope

The handbook is intended to be used to influence the design for readiness, supportability, and life cycle affordability. Pure design-related analysis is left to other references. Systems are described in terms of a number of important performance parameters in today's "performance based business environment." Examples of many of these parameters are shown in Figure 1.3-1. Some will be identified as KPPs for specific programs, but all are important in the systems engineering program. This handbook concentrates on just three of these parameters: reliability, maintainability, and certain aspects of the logistics support system. These three are the drivers of A_o and TOC, and can be used to focus the design and management teams at all levels of program decision-making.

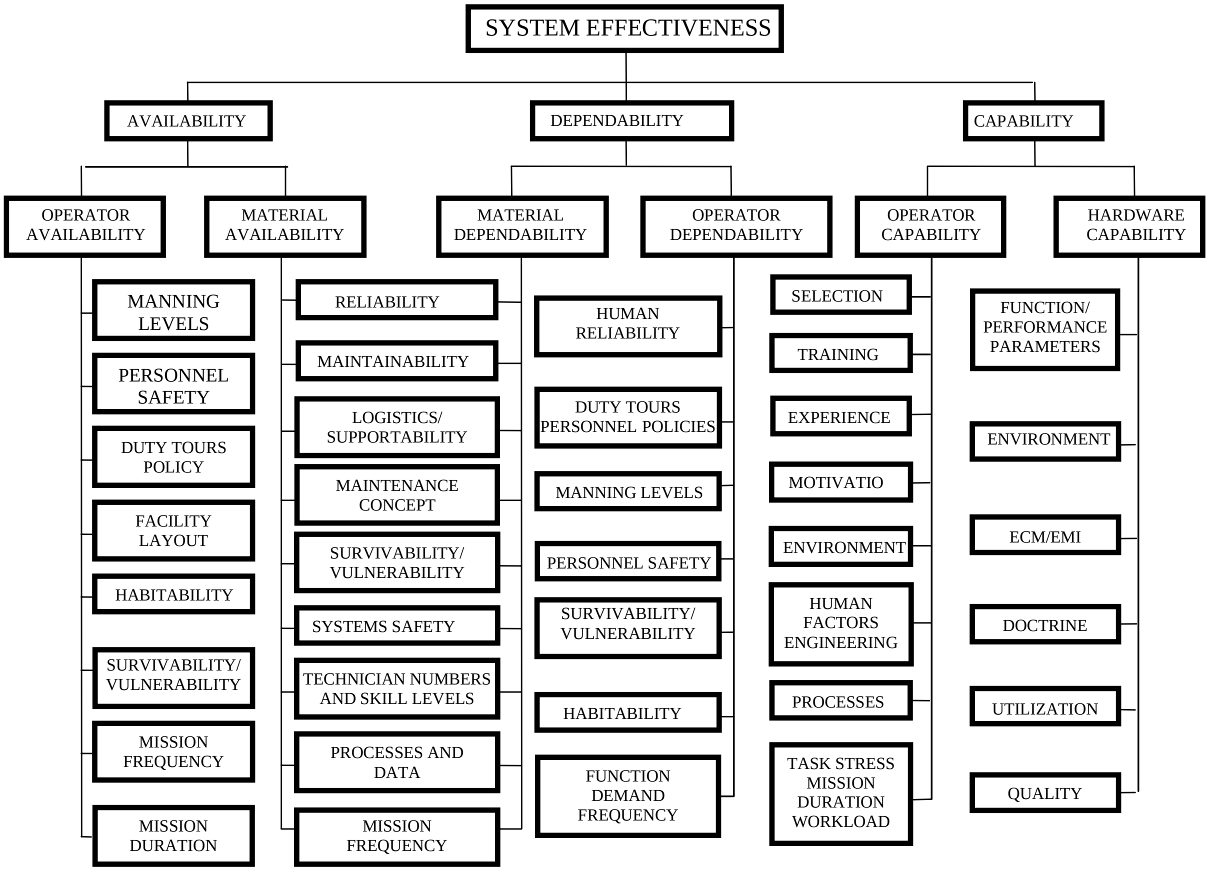

Figure 1.3-1. Systems Effectiveness

1.4 Why A_o and Cost of Ownership are Important

A_o and cost both satisfy the classic definition for a good Measure of Effectiveness/Figure of Merit (MOE/FOM).

- They represent the viewpoint of the stakeholders, i.e., those who have the right and responsibility for imposing the requirements on the solution.
- They assist in making the right choice by indicating "how well" a solution meets the stakeholders needs.

In his book, Logistics Engineering And Management,[3] Dr. Benjamin Blanchard states: "The use of an effectiveness FOM is particularly appropriate in the evaluation of two or more alternatives when decisions involving design and/or logistics support are necessary. Each alternative is evaluated in a consistent manner employing the same criteria for evaluation."

[3] Logistics Engineering And Management, Fifth Edition, Benjamin S. Blanchard.

A_o is a major contributor to Systems Effectiveness (SE). Although the exact definition and elements of SE can vary, Figure 1.3-1 shows some of the elements that may contribute to SE. Figure 1.3-1 shows that there are many candidate trade-off parameters in the capability, dependability, and availability areas.

Figure 1.3-1 also shows how these factors are related. Operational Capability (C_o) refers to the system's operating characteristics (range, payload, accuracy, and the resultant ability to counter the threat). C_o is the ability to counter the threat, in terms such as system performance, probability of kill, etc. A_o refers to the probability that the system will be ready to perform its specified function, in its intended operational environment, when called for at a random point in time. Operational Dependability (D_o) refers to the probability that the system, if up at the initiation of the mission, will remain up throughout the mission. Operational capability, operational availability, and operational dependability must be defined relative to the specific operational environment and operating scenario envisioned for a given system. Combined, they determine system effectiveness (SE). The system effectiveness of a specific system determines in large measure the effectiveness of the ship or aircraft platform on which it is installed.

1.5 Definitions of Key Models and Concepts

In addition to the following paragraphs, additional applicable terms, concepts, and acronyms are defined in Appendix B.

1.5.1 Brief Descriptions of Models

For decades, effective logistics managers have used models as part of the Supportability Analysis process. A model is a representation of systems, entity, phenomenon, or process. Two models are the Level of Repair Analysis (LORA) model, sometimes called the Repair Level Analysis (RLA), and the Life Cycle Cost (LCC) model. In addition, simulation models are used to assess achieved readiness. Many organizations have published guidance on the use of these models. Each model has an extensive user manual. In the following sub paragraphs, the two models are described in general terms. Appendix F provides some relevant web sites, both commercial and government, which have information on models currently in use and new products in development.

1.5.1.1 The Level of Repair Analysis (LORA) Model

The purpose of the LORA model is to solve for the lowest life cycle cost repair level for each of the repairable candidates in a subsystem work breakdown structure (WBS). A LORA model is normally run at the subsystem level such as a radar set or propulsion system.

Inputs to the model include the system reliability, maintainability, weight, cube, volume, etc. Also, data concerning logistics element resources needed to repair each of the candidates at each of the three levels of maintenance traditionally used for many systems. These levels are Organizational (O), Intermediate (I), and Depot (D). The model then goes through the following steps:

1. It first assumes that all candidates are non-repairable and are discarded upon failure at the O-level. Considering failure rates and the time to obtain replenishment spare from the source, the model calculates how many assemblies must be kept at each O-level site to satisfy requisitions. The model stores all costs for each repairable candidate.
2. The model next assumes all repairable candidates are sent to the D-level for repair. The model calculates all logistics elements required for repair of each candidate. The model again stores all of these costs by repairable candidate. This includes the reduced number of spares now needed at the O-level.
3. Next the model assumes all repairable candidates are repaired at the I-Level with sub-assemblies and repair parts going to the depot for repair. All of these costs are stored by repairable and by ILS element.
4. Finally, the model optimizes the repair level by comparing the relative costs for each repairable candidate for each of the options (i.e., discard at O-Level, repair at D-Level, or repair at I-Level), and selects the least cost option for each repairable candidate.

The model provides a comprehensive report for consideration by the analyst and lead logistician. The model assists the logistician in assigning a Source, Maintenance, and Recoverability (SM&R) code that defines where an item is removed and replaced (R&R) and where it is repaired. This key information is published in planning documents to guide logistics planners and also becomes input data for LCC and A_o models.

1.5.1.2 Life-Cycle-Cost (LCC) Models

The main purpose of a LCC model is to estimate the total costs associated with developing, acquiring, operating, supporting, and, at the end of its useful life, disposing of a system. A significant part of the LCC associated with any military system is the costs for initial logistics elements, which are procured with acquisition dollars and the annual and total Operating and Support (O&S) costs. In order for a complete LCC report to be produced, the LCC model must have the capability to capture R&D costs as inputs. Although the elements of LCC can be categorized in different ways, Figure 1.5-1 depicts a typical categorization of LCC elements. Note that not all of the cost elements shown in the figure will be applicable to all systems and products.

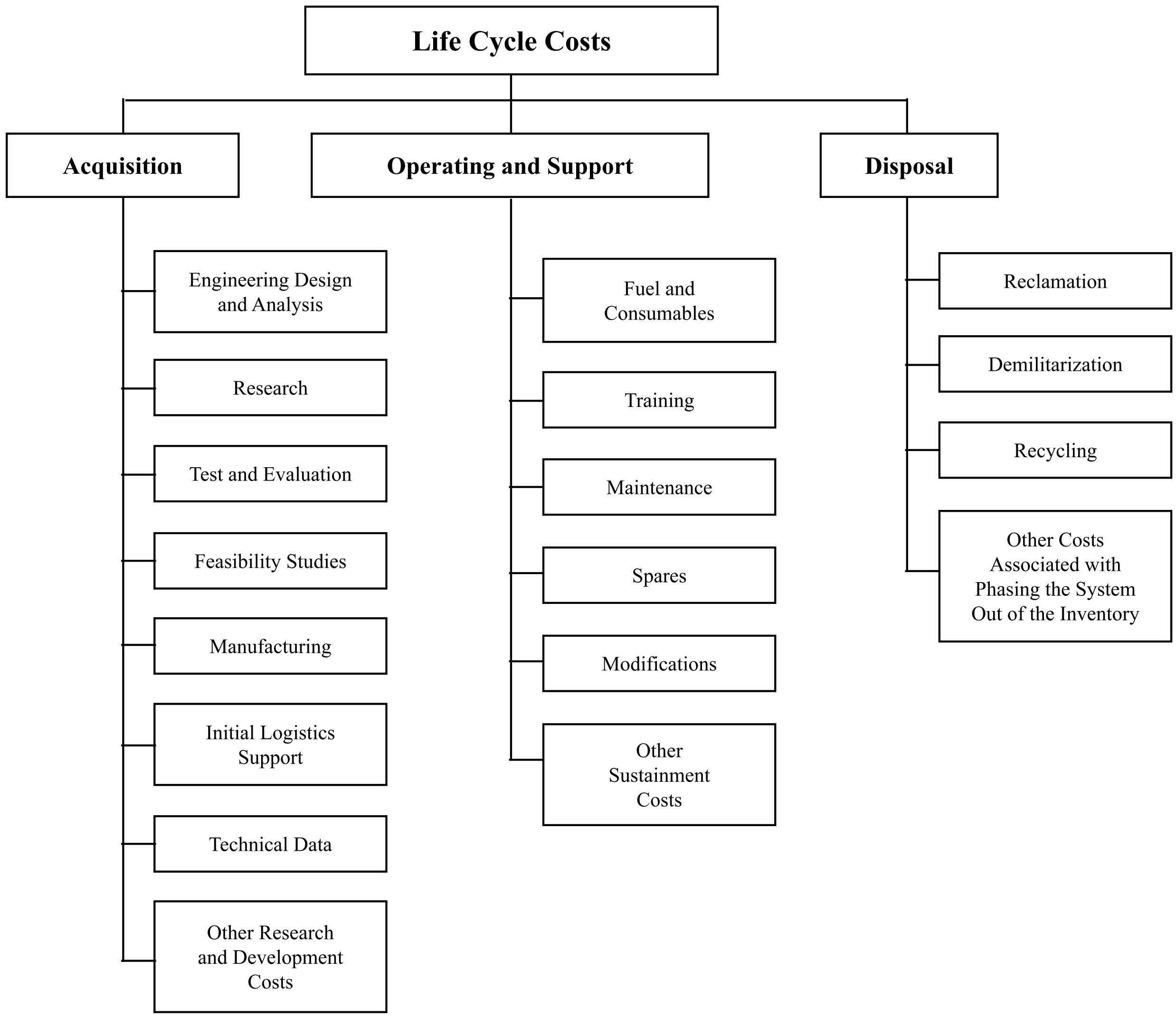

Figure 1.5-1. Typical Categorization of LCC Elements

1.5.2 Operational Availability and Sparing to Availability

A_o affects operations at the organizational level. It is a measure of the percent of time that an operational system is up and ready for use at any random point in time. When the system experiences a failure, the maintenance personnel must isolate the cause of the failure, remove and replace the failed item (or repair in place), and retest the system to verify that proper operation has been restored. The rapidity with which maintenance can be performed is a function of the R&M of the system and the efficiency and responsiveness of the support system. One key to responsiveness is having the right number of "spares" available when needed.

A model for sparing to sustain a given level of A_o needs essentially the same input data as LCC and LORA models. Operational needs, logistics infrastructure, and hardware information is fed into the model. The sparing to availability model calculates the number of each type of spare part to be kept at each maintenance level site to satisfy an A_o target value.

The model essentially divides the spares budget target by the failure rate for each spare part candidate. This process creates an index representing readiness per dollar spent for each part. The part with the highest index is selected. The calculations and selections are repeated until the A_o target is reached, constrained by the spares budget target.

1.5.3 The Acquisition Model

The milestones and program phases for military acquisition are illustrated in Figure 1.5-2. The figure is an adaptation of the model published in the Department of Defense 5000 series in October 2000. This general framework will be used throughout this handbook. Generally, all complex system acquisition programs will follow a similar sequence of design, production, deployment, and sustainment phases.

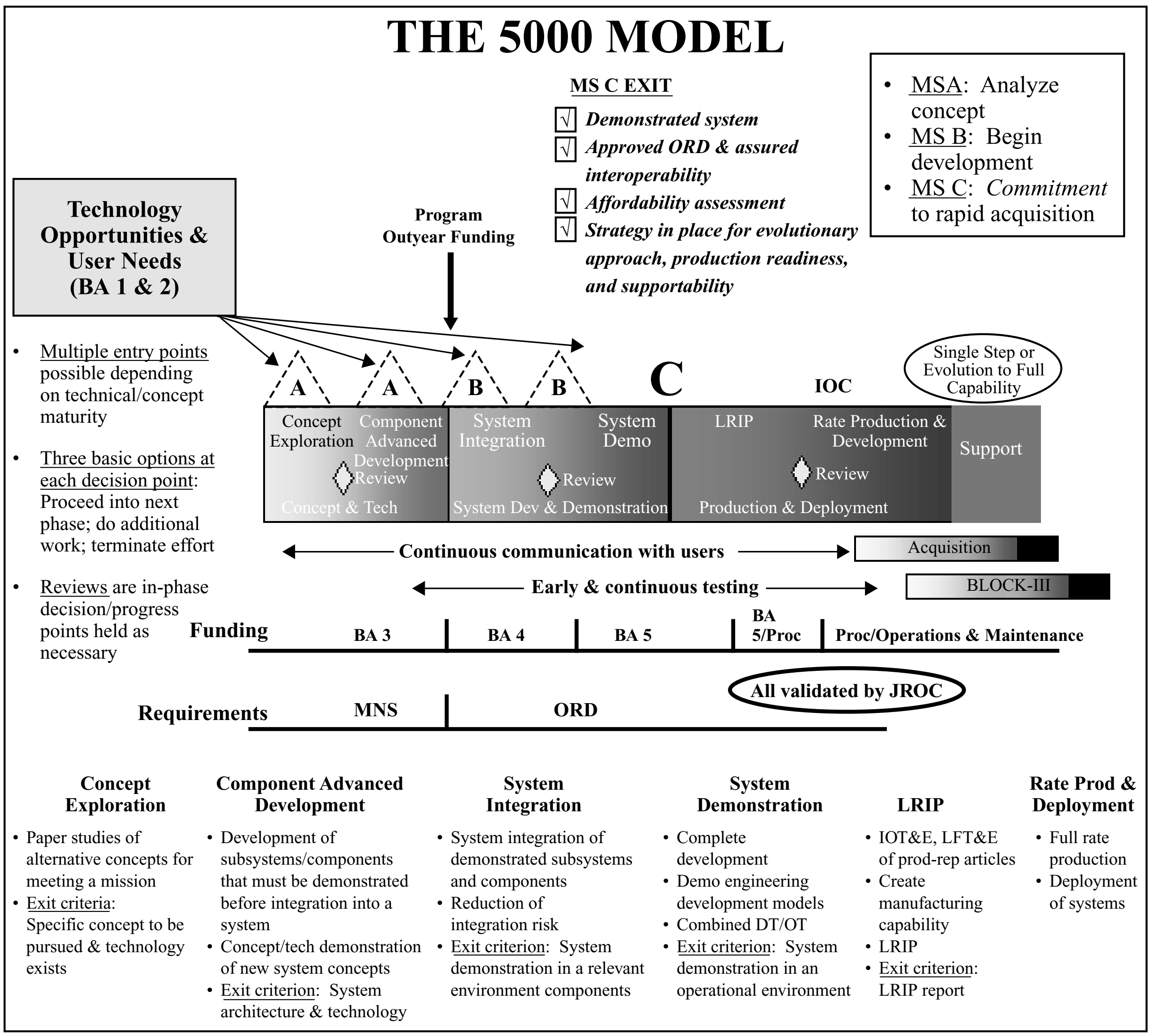

Figure 1.5-2. Acquisition Model Based on DoD 5000 Series Dated October 2000 (Note: The 5000 series were in revision when this document was written. However, with some mapping, the tasks and events described herein are still applicable.)