Open Systems and the Systems Engineering Process

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1. Introduction

The open system approach is both a technical approach to systems engineering and a preferred business strategy that is becoming widely applied by commercial manufacturers of large complex systems. It has the attention of DoD management who have mandated its use by DoD systems developers. Why? Because without such a change in system development practice, DoD risks being unable to maintain continued superior combat capability affordably!

Today, legacy weapons systems continue to be developed with their own, often unique and frequently closed, infrastructures, making upgrading or modifying them over their expected lifetimes (20 to 40 years) both problematic and expensive. Also, reduced procurement budgets and increased dominance of commercial technology cause acquisition managers to increasingly rely on commercial markets for affordable product development and support. So, as DoD's role shifts from being a technology producer to being a technology consumer, it relies more on commercial products whose design is not controlled by DoD and whose lifetimes are much shorter and more volatile than the weapons systems they support (e.g., years vs. decades). As a result, acquisition managers risk relying on unique products provided by a single supplier at high non-competitive prices and with little opportunity for technology insertion by other suppliers.

This paper discusses the need for a rigorous systems engineering process which incorporates open systems concepts and principles --- where resulting system designs more readily accommodate changing technology to achieve cost, schedule, and performance benefits by promoting multiple sources of supply and technology insertion.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY) 01-06-2002	2. REPORT TYPE	3. DATES COVERED (FROM - TO) xx-xx-2002 to xx-xx-2002

4. TITLE AND SUBTITLE Open Systems and the Systems Engineering Process Unclassified	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Hanratty, J. M. ; Lightsey, Robert H. ; Larson, Arvid G. ;	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME AND ADDRESS OUSD(A&T) Open Systems Joint Task Force xxxx, xxxxxxx	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME AND ADDRESS Open Systems Joint Task Force (OSJTF) 1931 Jefferson Davis Highway Crystal Mall 3, Suite 104 Arlington, VA22202	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
APUBLIC RELEASE
,

13. SUPPLEMENTARY NOTES

14. ABSTRACT
See Report.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19. NAME OF RESPONSIBLE PERSON
			Public Release	10	http://www.acq.osd.mil/osjtf/library/library_alpha.html (blank) lfenster@dtic.mil
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER International Area Code Area Code Telephone Number 703767-9007 DSN 427-9007

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39.18

2. The Need for an Open Systems Design Approach

An open systems design approach can allow a weapon system program office to achieve and maintain combat superiority in today's challenging acquisition environment. This approach focuses the design process on lowering the entire life-cycle costs (LCC) of weapon systems in contrast to current practice in which a disproportionate focus is placed on the short-term goal of having the lowest development costs. Figure 1 illustrates that 72 percent of LCC are incurred post-IOC during the service lifetime [1]. The ability of the open systems design approach to improve life-cycle supportability is becoming an even more important issue as DoD limits the number of new weapon systems procurements and extends the life of the systems currently fielded.

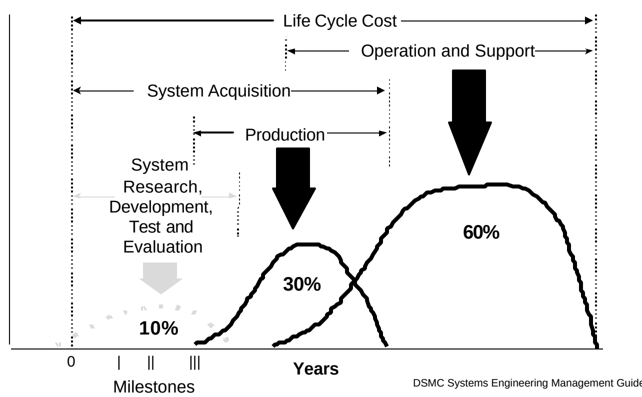

Figure 1. Life Cycle Costs

It seems clear that DoD managers should concentrate on doing things in systems engineering and development that will decrease costs during production and especially during the operations and support (O&S) phase. An open systems approach, basing the weapon system's design on open, commercially supported interface standards with the prospects of a large supplier and customer base, focuses the systems engineering process on developing system designs which consider life-cycle support requirements up front and that support system evolution throughout the system's life.

An open systems approach also mitigates the increased risks of obsolescence due to shortened technology cycle time. Obsolescence risks are significant because technology cycle time, sometimes on the order of months, far outpace weapon system development cycle time, typically 8 to 15 years. By the time a system is fielded, supporting technologies are often outdated -- the US. military cannot afford to be 3 or 4 technological generations behind what is available to the commercial market. Open systems designs, using commercially-supported interface standards permitting upgrade at a relatively low cost, specifically address issues of affordability and supportability associated with long lived system by facilitating evolutionary upgrade with new technology. Generally, this results in superior combat capability over the total system life-cycle, usually at a lower cost to the government.

Another reason that open systems have become so attractive is that DoD is no longer the dominant force in the market place and DoD's procurement budget has been drastically reduced. DoD no longer has the luxury of technology dominance, funded by seemingly unlimited budgets. In prior decades, DoD requirements drove development of new products and new technology. In the today's environment the opposite is true; commercial demand drives product and technology development. However, DoD can now take advantage of commercial innovation, research and development to drive down its cost of developing, acquiring and maintaining weapon systems, leveraging the commercial investment to make the most of available and shrinking defense funds. An open systems approach, using open interfaces supported by commercial and non-developmental components, can substantially facilitate this leveraging.

The bottom-line issue is not only cost: the lives of our servicemen may depend on shortened technology insertion cycle times. In a global market, everyone, including our potential adversaries, will gain increasing access to the same commercial technology base. The military advantage goes to the nation that has the best cycle time to capture the very best commercially available technologies, incorporate them in weapon systems, and get them fielded first. Moreover, since coalition operations with our allies place a high premium on interoperability, it is essential that our systems be compatible and capable of being sustained through a common logistics support structure. Open systems specifications and standards promote standard interfaces and interoperability with our friends and allies.

Each of these many issues will continue to substantively challenge past DoD acquisition practices throughout the foreseeable future. As a result, DoD finds itself with few alternatives but to drastically alter the way it develops, produces and supports its weapon systems. It is neither economically nor technologically feasible to continue traditional closed design approaches. DoD is increasingly compelled to move towards a more open weapon systems design alternative.

3. Open Systems Design Concepts

Simply put, the concept of open systems is a common sense approach that has substantial promise as an approach to meet DoD's continuing need to support systems over increasingly long life cycles in an environment of decreasing resources. In a time when the development of a complex system can span several generations of the faster moving technologies, open system architectures offer the tantalizing prospect of facilitating performance upgrades at affordable costs for the life cycle of the system. The potential and practice of open systems design as an emerging topic within the systems engineering discipline has now been with us for several years. In addition, the use of open systems has received the attention and support of the highest levels of DoD. In 1996, DoD issued a revised directive DoD 5000.2-R that instructs program managers to employ open systems as a design consideration in defense systems engineering [2] . The systems engineering process, with specific reference to the consideration of open systems designs, is integral to achieving the benefits of open systems designs.

While there are many definitions of open systems [3], most have a few characteristics in common. Open systems are those that can be supported by the marketplace, rather than being supported by a single (or limited) set of suppliers, due to the unique aspects of the design chosen. Open systems architectures are achieved by having the design focus on commonly used and widely supported interface standards. One might think in terms of the axle-wheel-tire interfaces employed on commercial cars. By adhering to common standards at the interfaces, the consumer is able to buy tires from a multitude of suppliers, rather than being forced to buy from a single source, as might be the case if the interface characteristics were unique to a single supplier. This ensures costs and quality that are controlled by the forces of competition in the marketplace. Furthermore, the continued support of the system is not subject to the risks associated with having a single supplier go out of business or cease supporting the standard. As the technologies associated with tires change with time, the customer can continue to upgrade and support his vehicle with tires that are built to the accepted industry standard (e.g., conventional sidewall bias-ply technology tires to steel-belted radial-ply technology tires).

However, despite all the high-level attention on open systems, DoD program managers must exercise some care and judgment in their application of the open systems approach. It does not represent a new approach that replaces and makes obsolete previous approaches to engineering complex systems. Moreover, managers should not simply implement an open standard without careful consideration of where (in the system hierarchy) it makes sense to impose standards nor should they simply grasp for a commercial item (CI) solution, whether or not the solution leads to the benefits of open systems architectures. Such actions may encourage program managers to declare that they are achieving open systems attributes, whether or not the system design is well thought out to take full advantage of the benefits that the open systems approach offers. This may give the appearance of achieving open systems architectures but, in fact, such short-sighted decisions work against the long term viability of the system. The open system concept does not replace the need for following a rigorous systems engineering process but, in fact, requires more rigor to ensure that open systems benefits are achieved.

4. Open Systems Applied Within the Systems Engineering Process

Systems engineering is fundamentally a problem solving process that translates needs and requirements as inputs into designs and products as outputs. The systems engineering process typically starts with problem definition as requirements are analyzed. Alternative solutions or system architectures are developed, usually initially through techniques such as functional analysis and data flow analysis. Alternative physical designs are then developed to satisfy the functional or data flows. Trade studies and risk analyses are applied to select a preferred design solution, and that solution is verified against the original requirements.

This process, properly applied, results in a flow down of requirements from the system level to the items below system level. As these requirements are flowed down, the design requirements for the items below system level are defined. Once these lower level design requirements are finalized, the design process proceeds to completion. The result is a design which associates physical entities with the functions that the system must perform, and is consistent with the levels of performance required and with the interfaces specified.

This process, applied without constraints, will lead to the design of a system in which every item is optimized to the requirements in terms of function, performance, and interface. Too often, the results in DoD have been systems that are unique in their designs, which perform their missions quite well, but which require unique equipment and parts to support them, and which can be supported only by a limited set of suppliers. This has historically been a prescription for "closed" systems that are both difficult and costly to support.

The challenge in DoD is to design systems to take advantage of open systems concepts where that makes sense, while continuing to meet the needs and requirements of operational forces. The solution is not to suddenly abandon good systems engineering and simply impose standard interfaces at some point in the system, nor is the answer likely to be found in indiscriminately importing CI solutions into the system architecture. Rather, the real answer is to be found in performing good systems engineering while, as DoD dictates, employing open systems as a design consideration from the outset. The challenge, then, is to integrate systems engineering and open systems design.

To this end, the use of architectures in DoD has become a preferred management approach for implementing an open systems approach [4]. DoD has implemented this concept by defining an interrelated set of architectures: Operational, System, and Technical (illustrated in Figure 2). Basically, the Operational Architecture specifies the "user requirements" which are used as inputs to the systems engineering process to eventually build the weapon system. The Technical Architecture and Product Lines constrain the system's design during the system engineering process. The System Architecture emerges as an output and is constructed to satisfy Operational Architecture requirements within the rules and standards defined in the Technical Architecture. Technical architectures are particularly important to the systems engineering process because they provide the building codes for implementing systems upon which engineering specifications are based, common building blocks are built, and product lines are developed. Note that while, each of these architectures by themselves build nothing, together they provide a management tool which facilitates evolutionary acquisition by supporting insertion of new technology, component reuse, improved weapon systems interoperability and the accommodation of evolving user requirements.

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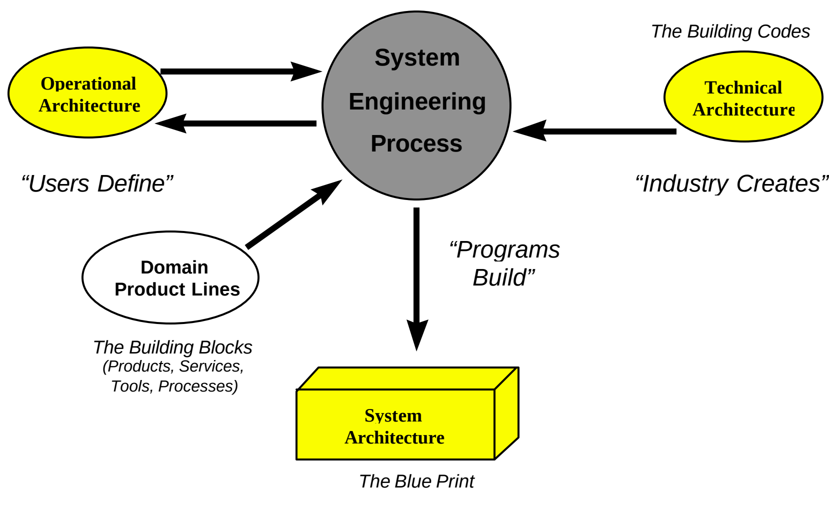

Figure 2. Architectures and the Systems Engineering Process

Who chooses the technical architecture? Does the government choose the architecture; does industry choose the architecture or is the architecture chosen in concert? The government may specify key performance attributes of system building blocks including internal interface standards. However, doing so without adequate input from industry stifles innovation, limits performance and increases cost by attempting to substitute our wisdom for that of the designer. If, on the other hand, we provide no guidance, we may encourage development of proprietary architectures, interfaces and components. That would leave DoD in a position where it must maintain and modify a unique product with a single supplier at a high, non-competitive price. Each program must chose a path between these two extremes. A desirable situation is for there to be a consensus among potential prime contractors and their key suppliers on application of widely accepted standards.

Using an open systems approach to the systems engineering process helps achieve an integrated design solution which is resilient to changes in technology throughout the life of the system. Open systems (engineering) achieves this resiliency in "life-cycle supportability" by engineering systems according to the following principles and practices (illustrated in Figure 3):

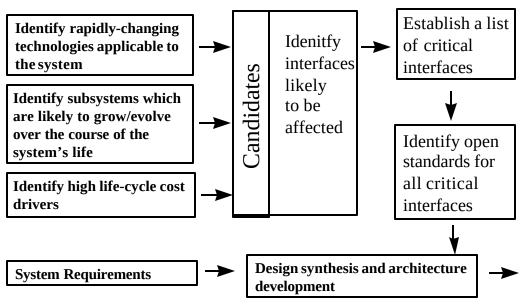

Figure 3. Open Systems Analysis for Integrated Design Solution

- Identify as critical the interfaces to subsystems or components which are likely to change due to their dependence on rapidly evolving technology, are likely to have increasing requirements, have high replacement frequency or have high costs. Such components present both the highest obsolescence risks and the greatest opportunity for future technology insertion.
- Use open standards for these critical interfaces that are supported by the broader community, , are considerate of life-cycle support requirements, permit evolution with advances in technology, and support technology insertion.
- Use a modular design approach combined with well defined standards-based interfaces among modules to isolate the effects of change in evolving systems, serving to reduce the need for redesign as the system is upgraded.
- Identify the lowest level at which the government maintains control over the interface standard, and anticipate how this level may change over time. Below this level the contractor is permitted to use its best, perhaps proprietary, practices to improve or discriminate its product in the marketplace.
- Verify all performance requirements and reevaluate their stringency. Reallocate requirements as necessary to permit the wider use of open standards throughout the system.

- Implement consistent conformance management practices to ensure that products procured for the system conform to the established profile so as to prevent being limited to one supplier who might unilaterally extend that interface.

The key to achieving the benefits of open systems designs lies in making open systems an integral part of the classic systems engineering process and in applying open systems at all stages of the product life cycle. The open systems approach to design will never replace or make obsolete that process -- if anything, it demands that the process be even more rigorously applied. As is illustrated in Figure 4, each of the major aspects of the systems engineering process must include consideration of open systems design concepts and principles:

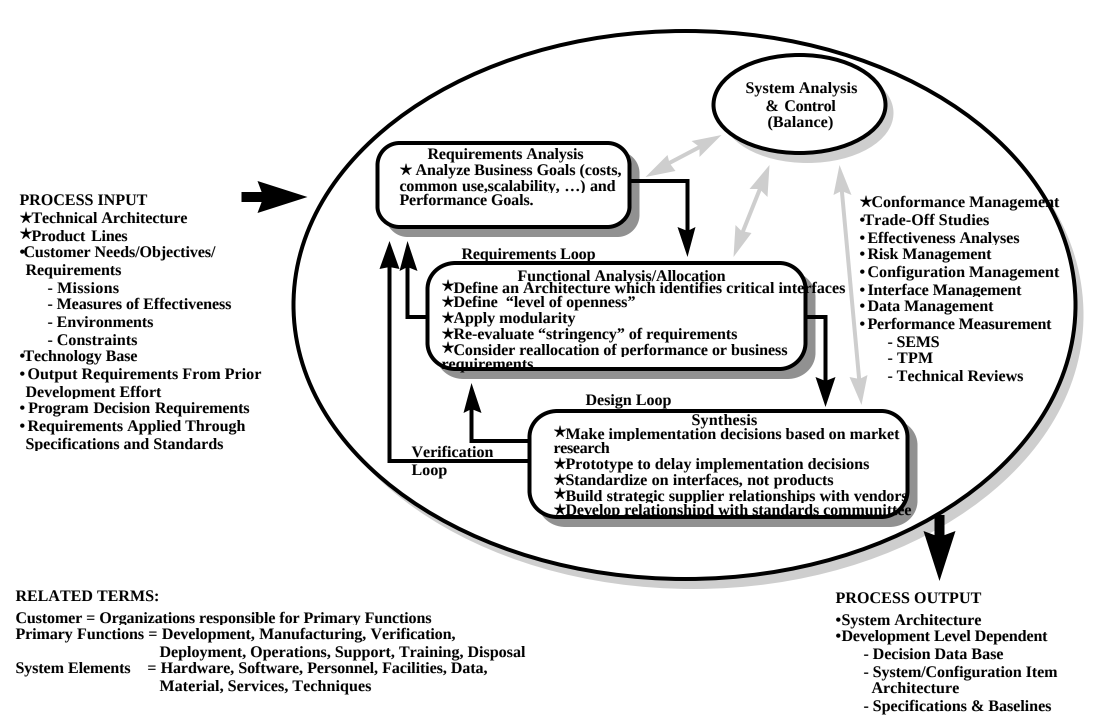

Figure 4. Integrating Open Systems and the Systems Engineering Process

Requirements analysis must emphasize the balancing of business goals (costs, common use, life cycle supportability, etc.) with technical goals (functionality, performance, interfaces, and other constraints). As the systems engineering process iterates, the requirements analysis step is revisited to consider cost-performance tradeoffs to meet most performance objectives while achieving as large as possible reductions in life-cycle costs. The stringency of requirements is reevaluated to consider the use of open standards for interfaces as performance requirements are balanced (weighed) against business requirements. To do this, engineers need to be better trained to incorporate life cycle cost in design and provided tools which allow them to rapidly assess life cycle cost impacts. Under any circumstances, users have a requirement for systems that are supportable and affordable, and these requirements demand that one consider open architectures as system elements are defined.

Functional analysis and allocation must define an architecture which provides a framework for identifying interfaces critical to achieving system business and technical performance goals. Requirements should be allocated with a view toward achieving functional modularity. Functional modularity can facilitate physical modularity and the use of open interfaces to support system evolution goals. As the systems engineering process iterates, this step is revisited to allocate functionality so as to modularize those components or subsystems which are dependent on rapidly evolving technology, have high replacement frequency or are high costs and to reallocate performance or business requirements as necessary to allow for the use of open interface standards during synthesis.

Synthesis and design should continue the search for alternative system architectures that will satisfy requirements. To be effective, good design synthesis demands an iterative approach that involves revisiting the functional allocations and developing alternative physical solutions until a balanced design (in terms of cost, performance, and risk) is achieved. Modularity should be used in system design where interfaces between modules are based on open, widely-supported interface standards. Modularity should be based on well-defined interfaces to isolate components that are likely to change over time (e.g., dependent on rapidly evolving technology, have high replacement frequency) or are high costs since these components present the highest obsolescence risks and the greatest opportunity for future technology insertion. Well-defined interfaces are used to decouple system components and define firewalls to contain evolution of lower level component upgrades and modifications, thereby minimizing future redesign, and possibly retesting, when components are upgraded. In addition, physical modularity should be aligned with functional partitioning to facilitate the replacement of specific subsystems and components without impacting others.

Design iteration should sequentially reconsider the allocations of function and performance that define the design requirements for each system component with the objective of achieving user (customer) requirements within an optimal open systems solution. From an open systems perspective, if this sequential iteration is stopped as soon as the first acceptable technical solution is achieved, there are two probable results: either the solution will be shown to (1) require unique designs that require new development, or (2) an open solution, if imposed at this point, will likely not meet all the requirements of the user. However, in most cases, a final design can almost certainly be developed that results in system architectures that include some items that are "open" and other elements that are not. Although open designs are the objective, it is neither necessary nor in some cases even possible that every element or item of most complex systems be totally open.

Systems analysis and control must include conformance management incorporating both implementation and applications conformance testing. The selected conformance approach must be fully defined and documented so that it is understood by all parties. The degree to which open systems benefits can be achieved will depend largely on how well the product design conforms to selected standards. Completely defined interface profiles will allow vendors to build standards-based components and allow users to design systems to use standards-based components. In all cases, candidate components should be tested against detailed system profiles to ensure that components conform to profiles.

5. Open System Design Challenges

The open approach to system design offers considerable benefits, already discussed, in terms of life cycle support, affordability and timely technology insertion. The approach also carries with it some substantial differences in the way that systems will be managed and supported. Since by its nature open systems designs will involve increased use of commercial and non-developmental items in systems architectures, the government will necessarily have to plan for significant differences in the way systems are managed from a technical perspective. These differences cut across almost every aspect of engineering management, and while space prohibits an exhaustive treatment, examples include the following:

- Standards based architectures lessen the degree of control that DoD can expect to exert. Changes, fixes, and updates will likely be under the vendor's control. This can have a significant impact on system support.
- Standards based elements of the architecture are likely to be faster and cheaper to acquire than a comparable developmental item but may take more time to integrate and test.
- Standards selection is risky. Acquisition will require substantially more knowledge of the current state of the art and the marketplace on the part of the government.
- Standards evolve with time. It is difficult to project the extent to which a given standard will endure. It's equally challenging to determine when to move from one standard to the next.
- Standards based architectures tend to change the focus of systems engineering from design to integration. The challenge is to achieve performance requirements without detailed control over the component design specification.
- An item, once integrated, may affect other system parameters. Commercial and NDI items make testing an on-going and continuing activity to verify that items can integrate successfully into systems.
- The use of commercial and NDI requires that support concepts be developed early in the acquisition cycle.

While this is hardly an exhaustive list, it makes the point that open systems engineering introduces new issues into the management of the technical aspects of programs. There are many potential benefits, but, likewise, there are challenges and problems that the manager must be alert to anticipate and overcome.

6. <u>Summary</u>

The objective of open systems acquisitions is to provide the warfighter the most effective weapon systems possible. An open systems approach to systems engineering facilitates this throughout the life of the system. Open systems designs provide an opportunity to achieve affordable designs which can more readily accommodate changing technology while promoting multiple sources of supply; however, to achieve good open systems designs first demands that a disciplined systems engineering approach be taken to defining the appropriate elements in the system to be opened.

Most systems will not be completely open in their architectures, but a well-engineered design will result in a design strategy that takes maximum advantage of the benefits available from opening the design. Associated with an open approach is the need to focus on and manage the interfaces between open system elements and other elements of the system. Choosing well-known and accepted industry standards and applying them in a controlled manner will go far toward achieving the desired results. Overall, the system architecture resulting from a system engineering process should be linked to a business case analysis. Architecture decisions should be traceable to performance, life-cycle cost, schedule, and risk. The alternatives for support, maintenance and upgrade should be evaluated.

For maximum benefit, an open systems approach should focus on planned use of designs across a system or domain. As designs are opened, managers must be aware of the fact that support and acquisition strategies will necessarily be impacted. These impacts must be anticipated and planned for from the outset during system design.

More open systems information and reference materials are available on the Open Systems Joint Task Force home page on the Worldwide Web at http://www.acq.osd.mil/osjtf

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