START Selected Topics in Assurance Related Technologies

Volume 10, Number 1

Interoperability

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Introduction

Interoperability is not a new term in the military vocabulary. It is difficult to determine when the term was first used, but two factors contributed to its emergence as an important military consideration:

- The integration of complex technology
- The growing reliance on joint operations

Interoperability is a primary goal for military operational capability outlined in Joint Vision 2020. To meet the operational goals of coalition and joint warfare, U.S. and allied forces must be interoperable. Many think of interoperability as forces being able to communicate with each other and share information.

These views of interoperability certainly are important aspects of interoperability but as we will see, interoperability means much more.

Evolution of Interoperability Concepts

The term interoperability has evolved over the years. It began primarily focused on equipment-level interoperability, soon was expanded to include inter-service and allied force interoperability, and has now evolved to include a "system of systems" perspective.

Equipment-level interoperability. For many years, interoperability was viewed as the ability of systems or key elements of systems to be able to work with each other. Interface standards, for example, ensure that items will properly work with each other. Frequency allocation ensures that communications will not be inadvertently jammed and that friendly forces can communicate with each other.

Inter-service and allied forces. At another level, interoperability addresses the ability of forces to work together. Developing small arms to use the same size ammunition, for example, facilitates joint operation of multi-national forces. Developing Air Force and Navy aircraft to use the same fueling nozzles and receptacles and their engines to use compatible fuel allows aircraft from either service to be refueled at any Air Force or Navy facility (or in flight).

System of Systems. As systems have become more complex, and as we have developed ways for systems to work together to form a "system of systems," interoperability has taken on another, more sophisticated meaning.

Strategic-thinking now requires military leaders to think in terms of capabilities, such as Time Critical Strike. Achieving such a capability entails many systems working in concert. For example, satellite, unmanned aerial vehicles, and Special Forces reconnaissance teams may be needed to find and identify a target. The target information must then be relayed in real time via communications systems to a command and control center (C^2C).

The C^2C must then combine this information with other information, such as the status and location of forces, select the weapon system or combination of systems that can most quickly hit the target, and order a strike. The selected systems must then move to a strike position (which will most likely be different for each system), acquire the target, bring its weapons to bear, and strike. Figure 1 gives one idea of how this system of systems might look.

Interoperability Definitions

Interoperability is defined in Joint Chiefs of Staff (JCS) Pub 1-02. The definition, which has been adopted by the North Atlantic Treaty Organization for use by its member nations, is:

> "The ability of systems, units or forces to provide services to and accept services from other systems, units, or forces and to use the services exchanged to enable them to operate effectively together."

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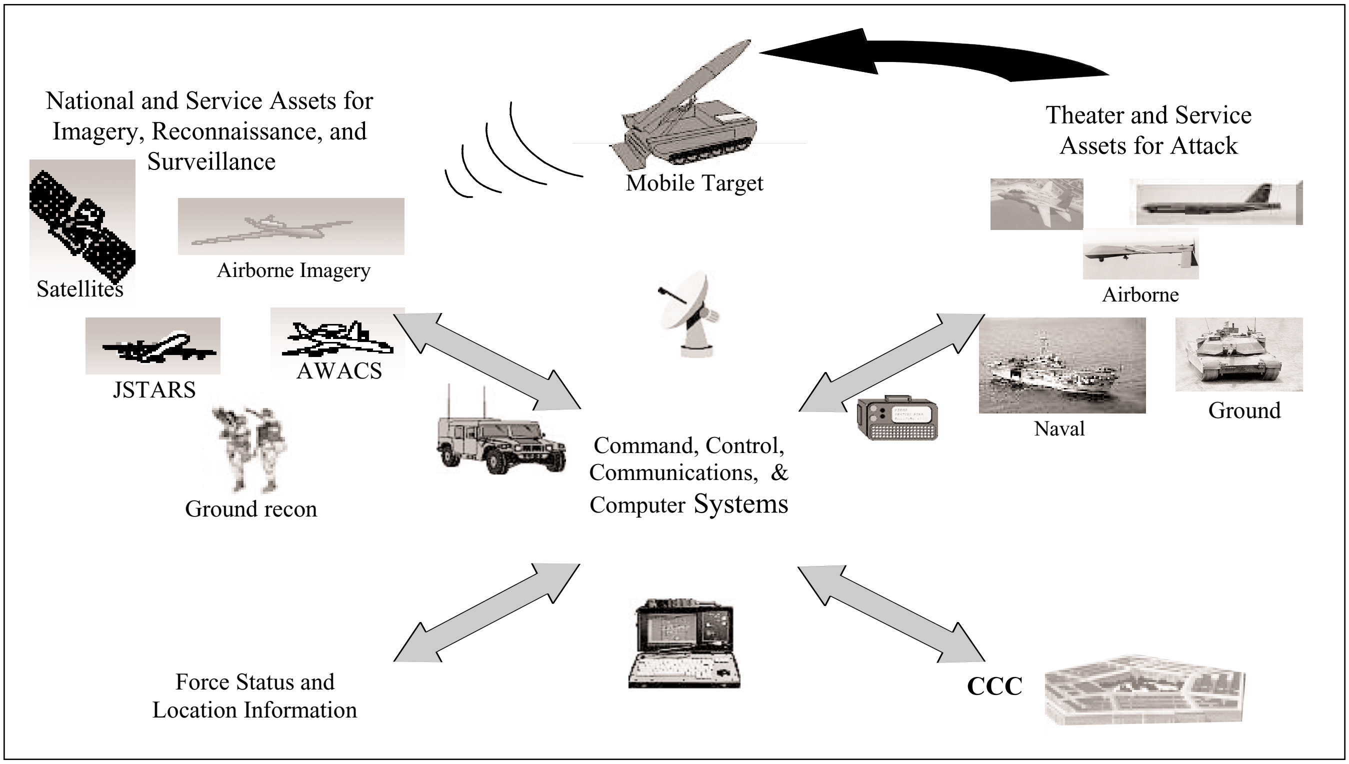

Figure 1. Conceptual Picture of a Time Critical Strike Capability

This definition is for Operational Interoperability. Other "official" definitions include the following for Technical Interoperability.

(1) The condition achieved among communications-electronics systems or items of communications-electronics equipment when information or services can be exchanged directly and satisfactorily between them and/or their users. The degree of interoperability should be defined when referring to specific cases. [Definition (2) in Joint Chiefs of Staff, Department of Defense Dictionary of Military and Associated Terms, as amended through December 7, 1998 (Joint Publication 1-02).]

(2) Interoperability is the ability of systems to provide dynamic interactive information and data exchange among C4I nodes for planning, coordination, integration, and execution of Theater Air Missile Defense operations. [Joint Theater Air Missile Defense Organization (JTAMDO), 1997. JTAMDO Master Plan. JTAMDO, Joint Staff, Department of Defense, Washington, D.C., Chap. 7.]

These definitions indicate that interoperability is a broad issue that cuts across many aspects of military operations and support systems. Although often associated with information systems, or more broadly Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems, interoperability extends across the battle management arena. It encompasses aspects of weapons and sensor systems, doctrine, future battle concepts and personnel.

As already discussed, it is widely accepted today that military forces are operating in an increasingly interdependent "system of systems" environment. Successful operations require that different systems, often developed and fielded by different organizations, operated by personnel from different organizations (often from different nations) including civilian emergency response teams, work together under stress.

Thus, interoperability involves interoperation of equipment, interoperation of military forces, interoperation among systems, and the interchangeable use of hardware and software across different kinds of systems.

Objectives

The Department of Defense has the following distinct objectives in seeking to increase interoperability.

- Better sustain the superior warfighting effectiveness of the nation's weapons systems
- Allow for quick insertion of new technology
- Lower costs for weapon system electronics (hardware and software)
- Facilitate more effective joint operations
- Provide capabilities not achievable with any single system

As the United States decreases the size of its military forces, it is essential not only that those forces be as technologically advanced as possible but that they be effective. When systems work in a complementary manner, as a cohesive whole rather than as disparate and separate entities, i.e., they are interoperable, effectiveness is increased.

Interoperability also requires and encourages design approaches that allow for new technologies to be easily and economically inserted. This capability is important given the rapid turnover of technology and is becoming even more important as the operational life of systems is extended.

One approach for allowing for the rapid insertion of *new technology is Evolutionary Acquisition and Spiral Development*. Although intended to reduce cycle time and speed the delivery of advanced capabilities to warfighters, evolutionary acquisition and spiral development also allow insertion of new technology over time. Briefly stated, evolutionary acquisition is a strategy for defining, developing, acquiring, and fielding incremental blocks of capability. Spiral development is an iterative process for developing a set of defined capabilities within one increment.

Developing common systems, communication systems for example, which are used on a variety of platforms not only improves interoperability, but it also reduces the overall cost of acquisition. Given the tight fiscal restraints that the Department of Defense has been faced with for the past several years (and, most likely, the foreseeable future), reducing acquisition costs is critical.

In addition to joint operations involving two or more of the US military services, interoperability is important to coalition operations involving US and allied military forces. As demonstrated in recent actions in Afghanistan, the Middle East, and the former Yugoslavia, the use of international coalition forces is becoming commonplace.

Finally, capabilities such as Time Critical Strike cannot be achieved with a single system. Instead, these capabilities can only be achieved through the integration of two or more systems that operate cohesively as a whole.

Implications of a System of Systems Approach

Defining capabilities. Developing requirements for a radio, radar, turbofan engine, aircraft, or tank is a complex and iterative process. Ideally, the design requirements are derived from the user's field performance needs, which in turn were derived from a threat or functional analysis.

For a system of systems, an added level of complexity is involved with developing requirements. The requirements must begin with the required or desired capability. The capability requirements begin with a threat or similar needs analysis. When the capability requirements have been defined, requirements can be allocated to the functional elements of the system of systems. These elements may be existing or planned systems. Or they may be new, undefined systems yet to be acquired.

The functional element requirements are used to develop requirements for the individual systems, which in turn serve as the basis for deriving lower-level requirements.

Given the complexity of developing and allocating requirements for systems of systems, modeling and simulation will become increasingly important tools.

Acquiring capabilities. Defense Acquisition Reform, like many predecessor reform initiatives, addresses in part the reduction of time and costs associated with acquiring a new military system. Acquiring a capability will be an even more difficult process. New policies and management approaches will no doubt be needed to make this process tenable.

Analyzing systems of systems. Whether it be analyzing requirements, alternative architectures, or the performance of a system of systems, more sophisticated methods will be essential. The foundation for these methods now appears to be simulation and modeling.

Testing systems of systems. Testing an entire capability may not be possible prior to deployment. Consequently, system and lower-level testing becomes even more critical.

Tools

Different tools are available for achieving interoperability. These include standardization and interchangeability, open systems architecture, modeling & simulation, reducing military-unique specifications, increasing reuse of hardware and software, and improving the cooperation among program offices.

Standardization and Interchangeability. Standardization and interchangeability are important, interrelated design factors. Interchangeability is one of the principal means by which standardization is achieved. Good examples of the close relationship between standardization and interchangeability are the standard size base for incandescent lamps and the standard size male plug for electrical appliances.

According to some military leaders, the infamous interoperability problem results from a lack of common standards in systems engineering. Each service builds its weapons systems to different performance specifications.

Standardization is a design feature for restricting to a minimum the feasible variety of items that will meet the hardware requirements. Standardization includes not only parts but also: engineering terms, principles, practices, materials, processes, software, etc. Standardization encourages the use of common items. It is important that maintainability engineers strive for the design of assemblies and components that are physically *and* functionally interchangeable with other like assemblies and components of the system. Standardization design will reduce the need for expensive support facilities at all levels of maintenance.

Standardization helps achieve the following goals:

- Minimize both the acquisition and support costs of a system
- Increase the availability of mission-essential items
- Reduce training requirements both in number of personnel and the level of skill required
- Reduce inventories of repair parts and their associated documentation

Despite the advantages offered by standardization, a system should not necessarily be built around a standard item – particularly if the standard item does not meet the required performance, has a record of poor reliability or costly maintenance; or the standard item may satisfy a safety requirement in most environments but not in the unusual environment for which it is being considered. Technological advances may also dictate the development of new material or provide a superior product to replace an existing one.

Interchangeability is the ability to exchange parts or assemblies between like equipments, without having to alter or physically change the item. This is an extremely important life cycle cost design requirement. Total interchangeability exists when two or more items are physically *and* functionally interchangeable in all possible applications – i.e., when the items are capable of full, mutual substitution in all directions. *Functional* interchangeability is attained when an item, regardless of its physical specifications, can perform the specific functions of another item. *Physical* interchangeability exists when two or more parts or units made to the same specification can be mounted, connected, and used effectively in the same position in an assembly or system.

The two broad classes of interchangeability are:

1. Universally interchangeable – Items that are required to be interchangeable in the field even though manufactured by different facilities.
2. Locally interchangeable – Items that are interchangeable with other components made by the same facility but not necessarily interchangeable with those made by other facilities. This may result from different sets of measurement units employed in their design and manufacture.

Open systems architecture. Today, the preferred approach to new system architecture is the Open Systems Approach. This approach is defined as integrated business and technical strategy employing a modular design and, where appropriate, defining key interfaces using widely supported, consensus-based standards that are published and maintained by a recognized industry standards organization. An Open Architecture, then, is an architecture that employs open standards for key interfaces within a system.

Modeling & Simulation. Together, Modeling and Simulation (M&S) can be defined as a discipline for developing a level of understanding of how the parts of a system interact, and of the system as a whole. The broad level of understanding that is achievable via this discipline is seldom achievable any other way. Definitions of model and simulation are:

Model: A model is a simplified representation of a system at some particular point in time or space intended to promote understanding of the real system.

Simulation: A simulation is the manipulation of a model so that it operates in a way that compresses time or space, thus enabling one to perceive interactions that would not otherwise be readily apparent because of their separation in time or space.

Computer simulation can be used as a tool to:

- Better understand and optimize performance of systems through trade-off analysis
- Verify the correctness of design
- Study day-to-day operations
- Develop "virtual environments" for training, war gaming, maintainability studies, etc.

Exchanging System Engineering Information. Sharing data during system development, among different stakeholders and between programs, is an important means of achieving interoperability. The Systems Engineering Data Representation and Exchange Standardization (SEDRES project has the mission "To extend, validate and standardize the Systems Engineering (SE) data model and nurture its practical implementation and multi-sector exploitation as a key enabler for the competitiveness of European industry."

Although a European-initiated project, SEDRES has international participation.

This project is directed at the development of an interface standard that will allow the complete set of tools in design of airplanes and spacecrafts and their avionics systems (hardware, software, mechanical design, and implementation, project management, etc.) to communicate in such a way that an integrated project support environment is available from commercial tools. The interface standard will be based on the STEP (Studies in technology, innovation and economic policy) standard, but will be extended to add the semantics appropriate to the aircraft industry.

An output from the effort is AP-233 (Application Protocol 233 "systems engineering"), an on-going initiative within ISO/STEP dealing with the standardization of System Engineering data. For more information on SEDRES and related efforts, go to the SEDRES web site at <http://www.sedres.com/>.

Reducing military-unique specifications.

Military-unique specifications often are counterproductive when trying to achieve interoperability. Specifying open system architectures, using performance-based specifications, and adopting a form-fit-function-interface (F^3I) approach to acquisition can enhance interoperability.

Increasing reuse of hardware and software.

Reusing existing hardware and software, when practical, can enhance interoperability. Using reference architectures, for example, can help ensure the interoperability of independently developed components and systems.

However, reuse should not be restricted to hardware and software. Knowledge bases, data, problem-solving methods, and other knowledge-base components can also be reused.

Improving the cooperation among program offices.

Historically, a given acquisition program office has tended to function in isolation from other program offices. In some cases, security restrictions necessitate this isolated environment. In many more instances, however, better lines of communication, sharing of information, and cooperative development of common subsystems and equipment would not only decrease costs but would improve interoperability.

Better cooperation among program offices can result in agreements about the architectural style for common equipment and interface definitions for the form, fit, and function of equipment that will be used in common or that must operate with each other.

Policy Implementation

Recently two DoD instructions have been reissued. These now make explicit the consideration of interoperability at each stage of the systems acquisition process. In effect, they provide the mechanisms within the system acquisition process itself to ensure that as systems are conceived, developed, tested, and fielded, their ability to interoperate in a system of systems environment is addressed at each step along the way.

CJCSI 3170.01A, "Requirements Generation System." This instruction requires all requirements documentation – regardless of acquisition category level – to conform to joint policy, technical architecture integrity, and interoperability standards. In addition, Joint Forces Command is designated as the JCS Chairman's advocate for joint warfare interoperability, and thus will play a critical review role in all systems requirements.

CJCSI 6212.01B, "Compatibility, Interoperability, Integration and C4 Supportability Certification of Command, Control, Communications, Computers and Weapon Systems." In final drafting, this instruction specifies three interoperability certifications to be accomplished for every C4I system and weapons system that interfaces with a C4I system. Additionally, it provides the process and format for developing interoperability Key Performance Parameters and Information Exchange Requirements for system requirements documentation.

Based on these policy documents, interoperability is now a key performance parameter for all systems and the support for interoperability with and among C4I systems is an integral part of systems planning and development. Defining interoperability tailored for each system and assessing this from requirements through testing is now part of the standard acquisition process. In addition, DODI 4630.5 and .8 are in revision to address interoperability. The previous versions of the DoD Acquisition Regulations (DOD 5000.1 and .2R) specifically addressed interoperability and it is expected that the new versions (due out in early 2003) will also.

The latter regulations address IT and NSS systems and institutionalize the Joint Integration and Interoperability (JI&I) process that is an important effort on the part of the Joint Forces Command to identify and address interoperability requirements of currently deployed forces.

Finally, in September 2001, the DoD directed that interoperability of currently fielded or legacy systems be given a new priority. Building on, and accelerating, the JI&I process, legacy systems now need to be reviewed, threshold interoperability needs defined and addressed, to provide a baseline level of interoperability for the fielding of new systems.

Summary

Interoperability is not a new concept. It began at the equipment level and slowly found application at the force level. However, as technology and the threat become more complex and sophisticated, the concept of interoperability has been extended to address a much more difficult challenge: systems of systems.

The system of systems idea is one irrefutably linked to the move from a system-level perspective to a capability perspective. This paradigm shift will require a fresh approach to developing requirements, designing, analysis, and test. Modeling and simulation will increase in importance as capability acquisition and deployment becomes more common.

With improved interoperability at all levels, the military services can:

- Better sustain a superior warfighting effectiveness of weapons systems
- Quickly adopt new technology
- Lower costs for weapon system
- Facilitate more effective joint operations
- Provide capabilities not achievable with any single system

For Further Study

1. "An Open System Approach to Weapon System Acquisition," Draft Program Manager's Guide, <http://www.acq.osd.mil/osjtf>.
2. CJCSI 3170.01A, "Requirements Generation System."
3. CJCSI 6212.01B, "Compatibility, Interoperability, Integration and C4 Supportability Certification of

Command, Control, Communications, Computers and Weapon Systems."
4. DODI 4630.5, Interoperability and Supportability of Information Technology (IT) and National Security Systems (NSS); 11 January 2002.
5. DODI 4630.8, Procedures for Compatibility, Interoperability, and Integration of Command, Control, Communications, and Intelligence (C3I) Systems; 18 November 1992.
6. SEDRES, Web Site <http://www.ida.liu.se/projects/sedres>.
7. DRR-1579/2-OSD, "A Strategy for Improving Interoperability of Weapon System Electronics," Volume 2, Iris Kameny et al, The RAND Corporation, February 1997.
8. USD/AT&L Memorandum, Evolutionary Acquisition and Spiral Development, April 12, 2002.

About the Author

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The Reliability Analysis Center is a Department of Defense Information Analysis Center (IAC). RAC serves as a government and industry focal point for efforts to improve the reliability, maintainability, supportability and quality of manufactured components and systems. To this end, RAC collects, analyzes, archives in computerized databases, and publishes data concerning the quality and reliability of equipments and systems, as well as the microcircuit, discrete semiconductor, and electromechanical and mechanical components that comprise them. RAC also evaluates and publishes information on engineering techniques and methods. Information is distributed through data compilations, application guides, data products and programs on computer media, public and private training courses, and consulting services. Located in Rome, NY, the Reliability Analysis Center is sponsored by the Defense Technical Information Center (DTIC). Alion, and its predecessor company IIT Research Institute, have operated the RAC continuously since its creation in 1968. Technical management of the RAC is provided by the U.S. Air Force's Research Laboratory Information Directorate (formerly Rome Laboratory).