



## An Architecture for Simulation Based Acquisition

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**I**n 1997 the Acquisition Council of the Department of Defense Executive Council for Modeling and Simulation adopted a vision for Simulation Based Acquisition (SBA): “an acquisition process in which DoD and industry are enabled by robust, collaborative use of simulation technology that is integrated across acquisition phases and programs.” Subsequently, a Joint Task Force was chartered to develop an SBA road map. As part of the Task Force, the Laboratory developed the architecture concepts covering the operational, system, and technical views that would promote interoperability and reuse of models and simulations. (Keywords: Acquisition reform, Modeling and simulation, Simulation Based Acquisition.)

### INTRODUCTION

When the Acquisition Council of DoD’s Executive Council for Modeling and Simulation was established, the Vice President’s National Performance Review (NPR) set a goal for cutting delivery time for new systems by 25%. In response to the NPR, DoD stretched this goal to a reduction of 50% in acquisition cycle time and set an additional goal of reducing total ownership cost. In December 1997, the Defense Systems Affordability Council identified Simulation Based Acquisition (SBA) as one of the top-priority efforts to achieve the NPR and DoD goals.

Noting the existence of a number of previous SBA-related studies, the Acquisition Council decided to establish a Joint SBA Task Force, which convened on 2 March 1998, to develop a road map for implementing SBA. A Terms of Reference (TOR) document for the Task Force was developed<sup>1</sup> that addressed notional architectures, technical challenges, ownership of modules in the systems architecture, opportunities for reuse,

investments, and recommendations that might be acted upon. The TOR also noted that change would be required in three areas: culture, process, and technical environment.

Since 1994, a number of SBA-related studies have cited the benefits of SBA-like practices,<sup>2-7</sup> none of which resulted in unified DoD action to implement SBA. The Task Force was intent on ensuring that its effort would result in a product that included recommendations. To guide its efforts in developing this product, the Task Force keyed upon the phrases “collaborative use” and “across acquisition phases and programs” in the SBA vision statement. Furthermore, the Task Force recognized that a structured process to acquire input from many stakeholders in the acquisition process was needed to guide its proposed solutions and recommendations.

The Task Force completed its effort in 6 months and delivered its initial road map to the Acquisition

Council for review and approval on 1 September 1998. In mid-1998, after several reviews and comment periods by the Services and members of industry, the Acquisition Council approved for publication the 4 December 1998 version of the road map,<sup>8</sup> which included a rewritten Executive Summary incorporating comments.

APL's principal technical contribution to the Task Force's efforts was the development of a notional architecture for SBA, with operational, systems, and technical views, as will be defined later in this article. We will first discuss an overview of the Task Force's approach and products and then describe a notional SBA architecture.

## TASK FORCE APPROACH

In response to the TOR, the Task Force formulated an approach consisting of three parallel but complementary paths to develop its recommendations for action (Fig. 1). The first path, labeled "Quality Function Deployment process," was a two-session Quality Function Deployment (QFD) process. QFD, a structured decision analysis tool, was used to gather customer input from approximately 45 representatives of government and industry. The results were used to identify target areas for the road map. APL structured the QFD process for the Task Force using the Task Force's work in developing notional architecture assessments and in consolidating recommendations from previous SBA-related studies as inputs to the two QFD sessions. The QFD process proceeded in a top-down fashion, beginning with the SBA goals in the vision statement and developing, in succession, prioritized strategies to achieve the SBA goals, SBA attributes, and actions to achieve those SBA attributes.

The second path, labeled "Task Force research, guest speakers, discussions, etc." in Fig. 1, consisted of

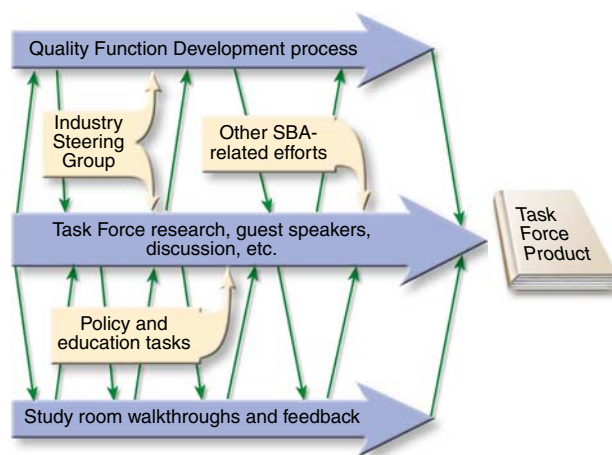


Figure 1. Joint SBA Task Force integrated parallel process.

literature reviews and related research, consultation with various authorities, and weekly discussions. Because of the broad scope of SBA, the Task Force decided to focus its initial developmental work in this path on the notional architecture task specified in the TOR. These architectural investigations had two complementary thrusts: (1) characterization of the current (or "as-is") state of DoD acquisition and identification of the principal shortfalls and (2) development of a notional "to-be" architecture to satisfy the SBA vision. This approach permitted comparison of the proposed to-be architecture with the shortfalls of the as-is state to help ensure that the proposed architecture would alleviate the principal shortfalls.

In the third path, shown at the bottom of Fig. 1, APL assembled an SBA study room for the Task Force. Here, work in progress was displayed and feedback was solicited, individually and in small groups, from members of the Acquisition Council and other DoD and industry subject-matter experts (SMEs). Expert feedback such as this influenced the Task Force's subsequent work.

## ROAD MAP RECOMMENDATIONS

Using the results of the QFD process, the SBA study room, and its own research, the Task Force provided recommendations for action that could be implemented, in either near or far term, in the following categories: management, architecture, policy and legislation, education and training, and industry.

In the management category, the Task Force collected a number of actions relating to the assignment of organizational responsibilities for implementing SBA, managing process-related activities, providing for funding, and developing metrics and return-on-investment (ROI) indications. Architecture recommendations defined organizational concepts and experimental efforts for collaborative environments and provided for the initiation of science and technology and research and development efforts as they relate to solving technical challenges identified in the road map. In the policy and legislation area, no specific policy or legal barriers to the implementation of SBA practices and procedures were identified. However, several changes (e.g., developing a single set of DoD SBA business practices, implementing a common SBA policy) were identified that would facilitate the attainment of SBA goals. Recommendations within the education and training category included incorporating SBA into existing DoD curricula taught at various program management seminars and DoD-sponsored schools, and establishing criteria on how and when to apply SBA practices and which application areas would provide the maximum ROI. In support of the Task Force's work in the ROI area, APL developed a methodology for assessing ROI on SBA. This methodology was not

included in the education and training category, but was provided as an example of a means of easily scoping ROI. Finally, recommendations were provided within the industry category in two subcategories: industry as a group and within companies. Those recommendations that dealt with industry as a group included such items as coordination across industry, involvement with standards and other professional organizations, industry education, and the monitoring of and participation in DoD initiatives.

## ARCHITECTURE

The Task Force's most substantial technical effort covered the development of concepts for an SBA architecture. The development effort began with an assessment of the current acquisition process, or the as-is state. Subsequently, architecture concepts were developed for the desired future state of SBA, or the to-be architecture.

The Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C<sup>4</sup>ISR) Architecture Framework document developed by the DoD C<sup>4</sup>ISR Architecture Working Group in December 1997<sup>9</sup> breaks down architecture into three main views: operational, systems, and technical. In order to develop a coherent path to the future, it is important that a baseline be established for the three architectural views. Although the C<sup>4</sup>ISR Architecture Framework document focuses on architectures that will support warfighter interoperability for real-world operations, the SBA Task Force found it useful in providing structure to the modeling and simulation (M&S) domain. Figure 2 is a simplified depiction of each of the three architecture views that were used in developing the as-is and to-be architectures.

The operational architecture view shows the organizations, activities, functions, information flows, and processes to accomplish a particular mission. For systems

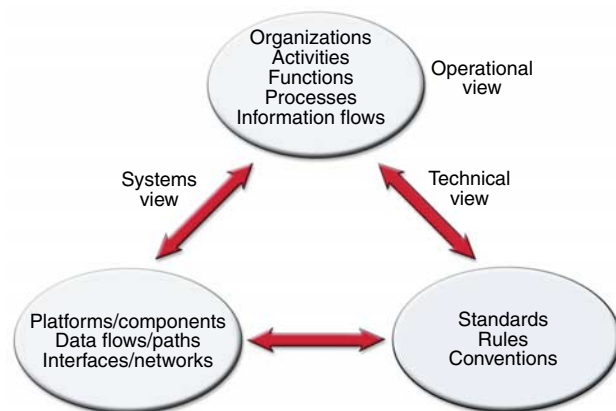


Figure 2. Three views of an architecture.

acquisition, the mission is to provide a means for acquisition managers to deliver cheaper, faster, and better combat systems to warfighters. APL developed an operational architecture view for SBA to examine areas such as organizational relationships, policies, business practices, environments, and processes from which systems and technical architectures could be derived and analyzed by the Task Force.

The Task Force developed a systems architecture view to highlight the physical components that support the operational architecture view, such as platforms, data flows, interfaces, networks, models, simulations, and simulation frameworks. The systems architecture view was used, in turn, to determine if new technologies may be required to fulfill future operational architecture requirements. The systems and operational architecture views were considered in developing the technical architecture view.

The technical architecture view consists of standards, rules, and conventions that must be followed to implement the systems and operational architecture views. The as-is technical architecture for systems acquisition was examined to identify inhibitors to interoperability, simulation reuse, data sharing, and leveraging resources and processes across acquisition phases and programs. Throughout the process of developing the to-be SBA architecture, each of the three views was compared and modified to ensure consistency and that the recommendations in each of the three areas were mutually supportive.

### As-Is Architecture

Figure 3 is a high-level depiction of the current or as-is operational architecture view for systems acquisition. In this environment, integrated product teams (IPTs) and working groups have been formed within DoD and industry as part of Integrated Product and Process Development to support the full range of functional disciplines from planning to operations. However, many of the participants who are intimately involved in later stages of the life cycle, such as testers, maintainers, trainers, and operators, have limited involvement in functions at the earlier stages. In addition, IPTs within each program office are aligned under the acquisition functional areas such as systems engineering, test and evaluation, manufacturing and production, and operations and support, with limited connection to the functional areas outside a particular program office.

Many of these IPTs tend to be formed along functional lines and to use specialized and incomplete sets of tools. These tools are supported by a wide variety of specialized databases. Another characteristic of the as-is operational architecture is the limited linkage among the senior decision-making function and other

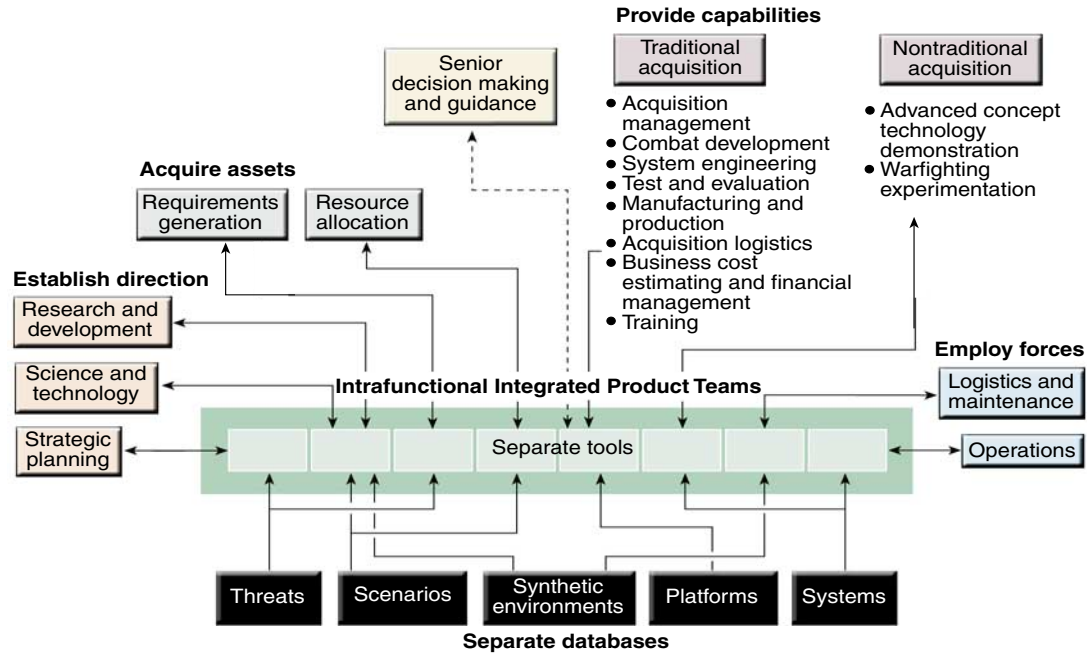


Figure 3. As-is environment for systems acquisition.

functions of the acquisition system. At the time the Task Force produced the SBA road map, few tools and facilities were available to provide senior decision makers with a window into other functional areas. The Navy Acquisition Center of Excellence and the Air Force Theater Battle Arena are examples of facilities that have been used effectively to demonstrate the potential utility of new concepts, technologies, and systems to senior leadership through advanced graphics systems and M&S, respectively. Information technologies are being developed by organizations like the Defense Advanced Research Projects Agency to support strategic-level decision making. As these technologies are introduced into command centers and facilities like the Acquisition Center of Excellence and Theater Battle Arena, senior leaders and their staffs should be able to interact with various functional areas to gain additional insight into SBA activities.

While reviewing the current systems architecture, the Task Force characterized the M&S tools and their uses within DoD acquisition programs. M&S tools were characterized by their scope and level of detail (i.e., engineering, engagement, etc.), class (i.e., constructive, live, or virtual), and the functional area they support. Each acquisition milestone phase, from mission needs to disposal, was examined to determine the primary uses of M&S tools and how they support each functional discipline such as management, logistics, training, test and evaluation, systems engineering, and others. A number of shortfalls were identified, ranging from lack of tool reuse and interoperability to poor documentation standards for accreditation evidence,

which were considered to impede the efficient and effective use of system architecture components in today's acquisition process.

Once the systems architecture was described, those DoD and non-DoD standards and conventions and their interactions with DoD and non-DoD environments—composing the technical architecture—were examined. Models and simulations currently used within both environments have been developed using various standards and conventions, even with the current desire to migrate to the Joint Technical Architecture (JTA) standards,<sup>10</sup> including the High Level Architecture (HLA). The HLA is a software architecture for composing interoperable simulation environments from reusable simulation components. Program managers currently have no incentives to conform to a set of standards that would facilitate interoperability and reuse.

### To-Be Architecture

The notional to-be SBA architecture was designed to accelerate progress toward achieving the fundamental goals described in the SBA vision and to directly address current M&S shortfalls described in the as-is architecture. High-level descriptions of the three views of the notional to-be architecture (operational, systems, and technical) follow.

#### To-Be Operational View

The operational view of the to-be SBA architecture describes a fundamental concept for how government, industry, and academia can collaborate and share

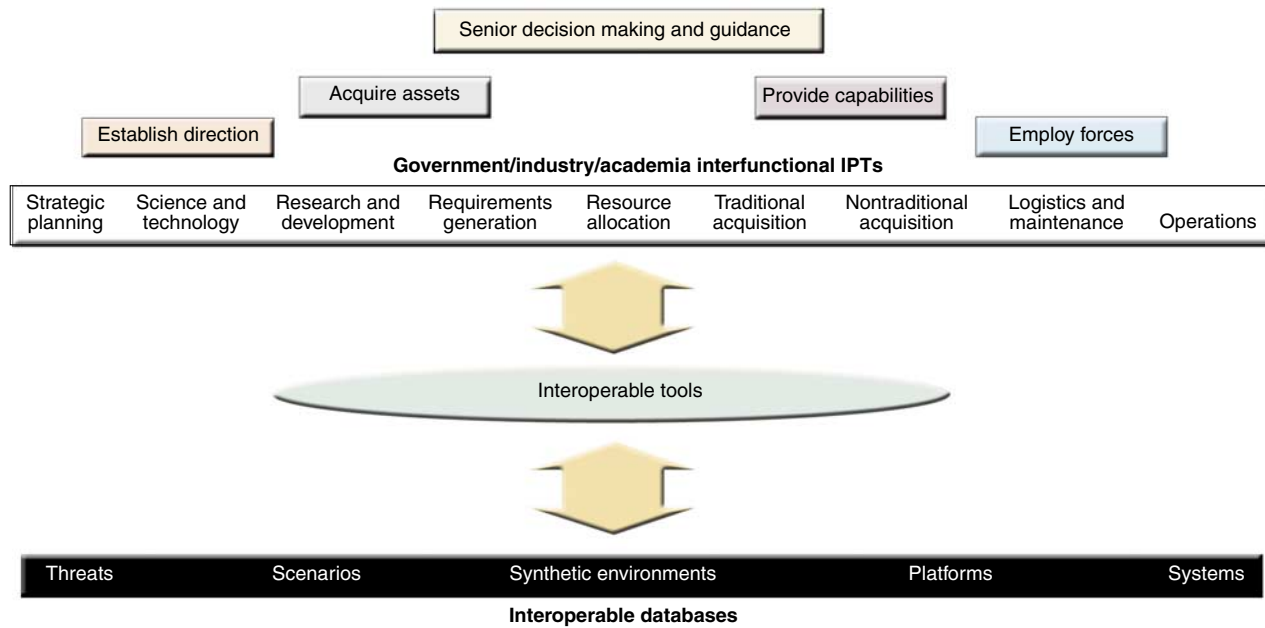


Figure 4. To-be collaborative environment.

information more effectively throughout the acquisition process. This concept, which is called a collaborative environment (Fig. 4), consists of SMEs supported by interoperable tools and databases, authoritative information resources, and product and process models that are focused on a common domain or set of problems. Programs use and reuse the resources intrinsic to an appropriate collaborative environment throughout the product life cycle, facilitating communication and cooperation within interfunctional IPTs and reducing overall program cost.

Collaborative environments are most effective when they are organized and interrelated, sharing resources and passing information from one level of aggregation to another. Six levels of notional collaborative environments were described in the road map (strategic, operational, mission area, product area, system, and subsystem), as shown in Fig. 5, to illustrate how collaborative environments could be defined based on an organizational and functional hierarchy. The Task Force noted that the biggest potential payoff expected through the use of collaborative environments was in the mission and product areas. The specific definition and evolutionary implementation of

collaborative environments are the responsibility of the Office of the Secretary of Defense, the Services, and defense agencies. The Task Force recommended that ownership of individual collaborative environments be closely aligned with the organizations that have real-world responsibilities in those area. Collaborative environments that are well-defined, recognized, and

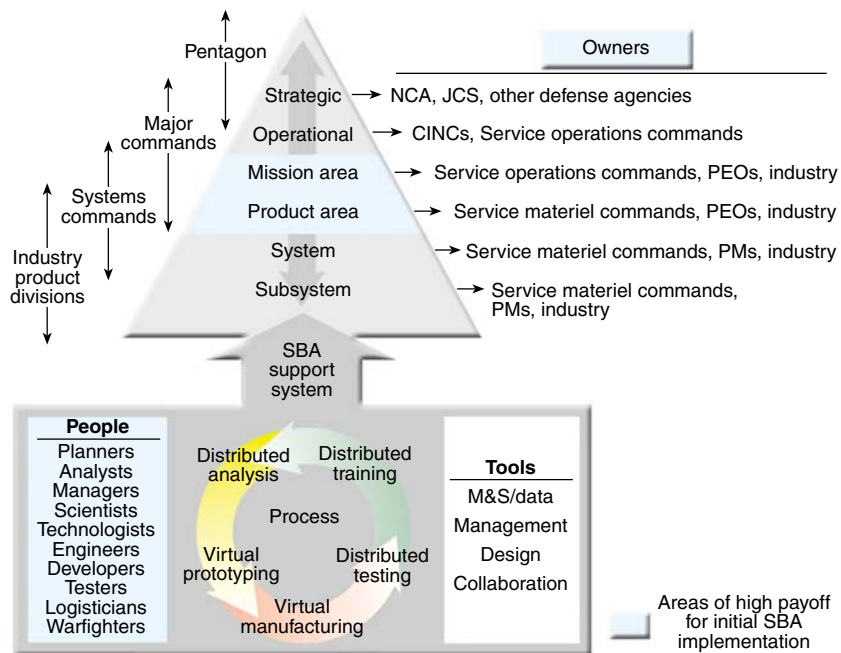


Figure 5. Proposed levels of a collaborative environment. (CINC = Commander in Chief, JCS = Joint Chiefs of Staff, NCA = National Command Authority, PEO = Program Executive Office, PM = Program Manager.)

institutionalized will significantly reduce duplication and dilution of investments in SBA.

**To-Be Systems View**

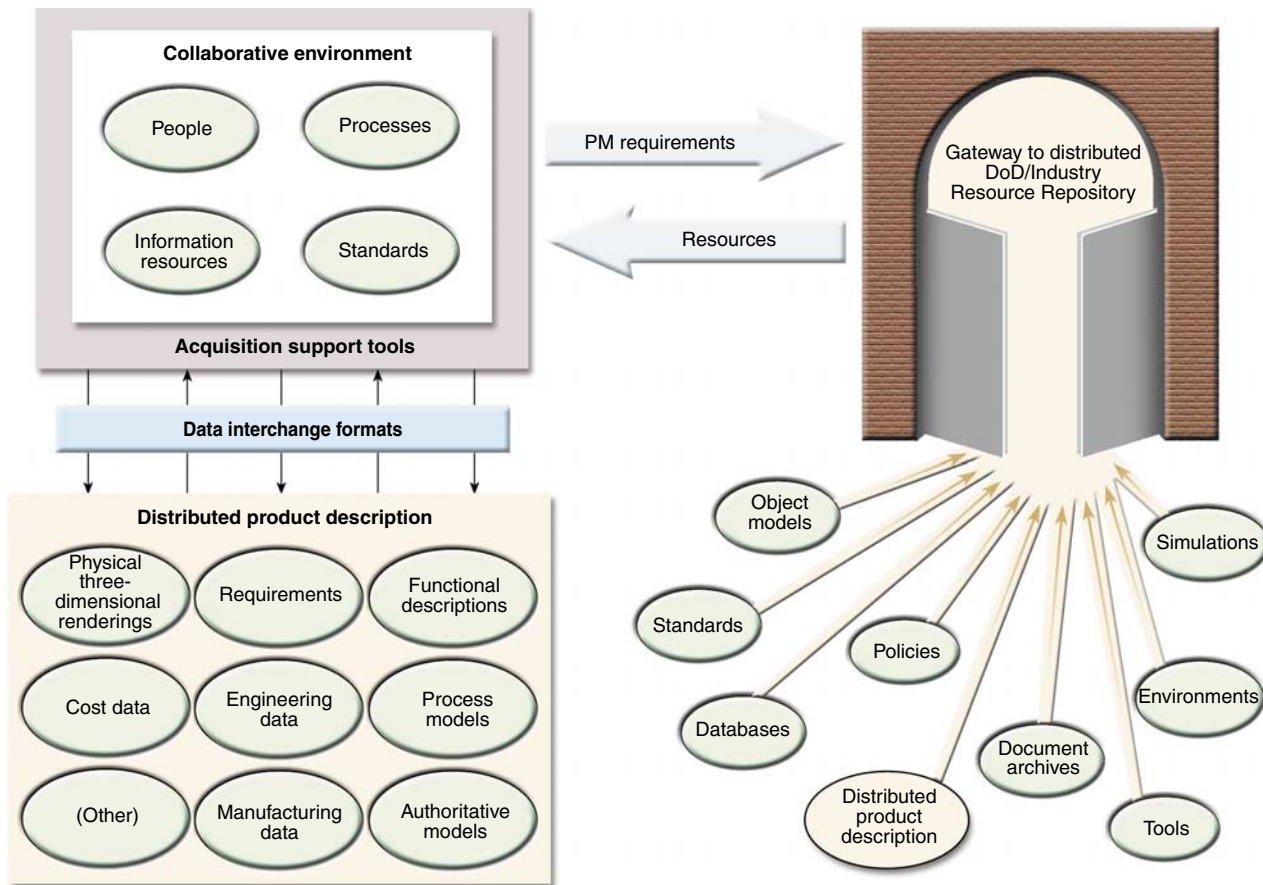
Collaborative environments represent the fundamental operational architecture concept upon which the implementation of the SBA vision is based. The hardware, software, and information resources that compose a collaborative environment (along with their interrelationships) together define a systems view of the SBA architecture. On the basis of long-term efficiency and cost-reduction goals identified for SBA, this systems architecture view is required to exhibit (at a minimum) the following general characteristics:

- Facilitate collaboration and effective use of M&S within the systems acquisition process via ready, dependable access to supporting tools, resources, and infrastructure
- Facilitate interoperability between and reuse of models, simulations, data, and other infrastructure components (networks, facilities, etc.) across different functional disciplines and programs and between government and industry

- Maximize the use of existing government off-the-shelf/commercial off-the-shelf products and standards to minimize new tool and infrastructure development
- Be open, scalable, and flexible, allowing many different implementation approaches

Figure 6 depicts the top-level view of the SBA systems architecture. The three primary components of the architecture are collaborative environments (implemented using a common Collaborative Environment Reference Systems Architecture, or CERSA), a DoD/Industry Resource Repository (DIRR), and distributed product descriptions (DPDs). The DIRR and the DPDs are interconnected using Web technology, have a configuration control process, and use encrypters and firewalls for access control.

From a systems perspective, the collaborative environments component represents an alignment of functional area experts and supporting sets of reusable, interoperable tools and resources with particular classes of applications. For example, product-focused collaborative environments would consist of personnel and hardware and software resources that typically address the design, development, and evaluation of products in



**Figure 6.** Top-level systems view of SBA architecture.

that class (e.g., avionics, weapons, ground vehicles). Collaborative environments are intended to be persistent, providing managers of new acquisition programs with a reusable framework of tools, resources, and SMEs within the bounds of a given application domain.

The DIRR provides a Web-technology-based distributed repository of tools, information resources, and generic infrastructure components for use within and reuse across acquisition programs. The DIRR can be considered to represent the union of the capabilities provided by all collaborative environments, affording a means for any individual collaborative environment to share local resources with other domains and for a collaborative environment to access and use external resources as required for new applications. The gateway to the repository provides a directory structure, browsers, and tailored commercial search engines to enable users to quickly discover resources (each described by a common metadata format) of interest to them. Intelligent user interfaces provide extensive online assistance for using the repository and building complex search patterns. Firewalls and encryption devices are also included within the repository (as required) to support access and distribution of classified data and to enforce access restrictions on proprietary materials.

The DPD component defines a distributed collection of product-centric information that is interconnected via Web technology into what appears (to the user) to be a single, logically unified product representation. DPDs are composed primarily of three types of information: product data, product models, and process models. Product data specify the characteristics of a product at any point in its development cycle, including requirements, program management data, cost data, engineering data, manufacturing data, and test data. Product models are authoritative representations of a product's behavior, or performance, or both. Process models are used to define the business operations necessary to define, develop, manufacture, deploy, and dispose of the product throughout its life cycle. DPDs may also contain other relevant product-related information, such as functional descriptions of product behavior and various categories of applicable metadata (e.g., verification, validation, and accreditation status).

DPDs provide a common reference for integrated product and

process development when coupled with appropriate automated support tools and a valid workflow model. That is, a DPD provides a common product view to all IPT participants at all times during the acquisition process, allowing simultaneous evaluation of the current product configuration from the perspective of each functional discipline. Thus, product designers can measure the performance of a product at the same time that product manufacturers evaluate the producibility of the product and logisticians assess the supportability of the product (assuming proper configuration management and version control).

An illustration of the CERSA is presented in Fig. 7. Tools and resources within a given collaborative environment are always selected to maximize the overall effectiveness and efficiency by which applications are addressed within that domain. However, such flexibility may also introduce the danger of "stovepipes." That is, it is entirely possible for any given collaborative environment to focus and align its internal structure and supporting resources so strongly on a particular class of applications that cross-domain tool reuse and data sharing are impeded. For this reason, a reference systems architecture for all DoD collaborative environments is needed that globally defines the types of components that one can find in a collaborative environment and (at a high level) how these components

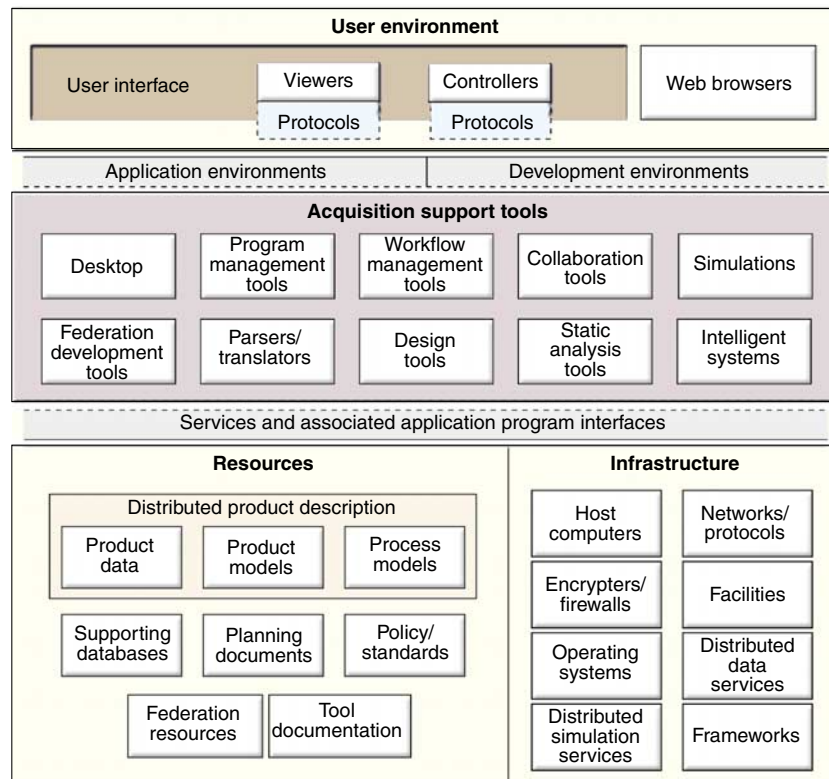


Figure 7. Collaborative Environment Reference Systems Architecture.

interrelate. The primary intent of this reference systems architecture is to highlight the required “piece parts” and opportunities for interface standards associated with a collaborative environment while providing developers with a high degree of flexibility regarding specific implementation approaches.

The architecture is organized according to a layering strategy, where each layer represents a logical grouping of components that access and use components of underlying layers in order to perform certain types of functions. A short summary of the CERSA is provided next.

The topmost layer of the architecture, the user environment, includes those system components that directly interface with the end users of the system. This includes the user interface (viewers and controllers) and external communications software (e.g., Web browsers) to provide an external interface to the DIRR and other collaborative environments.

The next layer of the architecture, acquisition support tools, includes those systems components that directly access, manipulate, and generate product information for the purpose of gaining knowledge and insight about the product. The classes of tools that support acquisition programs are identified in the architecture diagram and range from simple desktop support (e.g., word processors, spreadsheets) to far more sophisticated tools to support program management, process management, and product design (e.g., software such as CATIA and AutoCAD).

Two critically important elements of this architectural layer are the models, simulations, and information technology tools that support product design and development and the tools that support the development of HLA federations of simulations. The fundamental concept that underlies the use of simulations and associated tools in the SBA systems architecture is known as a persistent federation.<sup>11</sup> Persistent federations can be loosely defined as a highly stable superset of simulations, federation products (e.g., the Federation Object Model, the *Federation Execution Planners' Workbook*), and knowledgeable people that are associated with a longstanding set of high-level requirements under an appropriate management structure. As new applications are identified, federations are formed by reusing an appropriate subset of the simulation superset and defining appropriate modifications to relevant, reusable federation products. The concept of a collaborative environment represents an important extension to the persistent federations concept, incorporating the full set of tools and information resources relevant to acquisition programs.

In addition to the tool components themselves, there are two optional sublayers that may be defined at this level of the architecture. First, in circumstances in which the tools are designed and implemented as

client programs that operate from a core set of common services, the architecture explicitly identifies these common services as a sublayer below the tool components. These services would normally be accessed via an appropriate application program interface using an appropriate infrastructure component (e.g., Object Request Broker). Second, there may be circumstances in which tightly integrated application (product development) and (software) development environments are desirable or needed in certain types of collaborative environments. These types of environments interconnect selected components from multiple layers into a single unifying framework and are recognized as an optional sublayer above the tool components.

The next layer of the architecture is composed of two partitions: resources and infrastructure. The first partition identifies the classes of information resources that are necessary to conduct an enterprise. This partition includes primarily reusable libraries of supporting documentation resources and reusable data resources for product design and development. Note that this partition includes the reusable databases, planning documents, and federation resources necessary to support the concept of a persistent federation, and also contains the DPDs themselves.

The second partition, the infrastructure, identifies the basic equipment (hardware and other facilities) and low-level software mechanisms that enable basic enterprise operations and the processing and exchange of product information within a collaborative environment. The infrastructure includes hardware components such as host computers and physical networks as well as advanced software services to support distributed simulation applications (e.g., HLA runtime infrastructure services) and distributed database management.

### *To-Be Technical View*

The to-be technical view specifies the standards and local conventions that govern the implementation of collaborative environments. As discussed earlier, these collaborative environments should be developed in alignment with the CERSA. However, it is important to recognize that the architecture components specified in the CERSA simply enable information sharing and reuse and that appropriate sets of supporting standards must be defined to achieve the interoperability, reuse, and generalized efficiency and cost-savings goals identified for SBA.

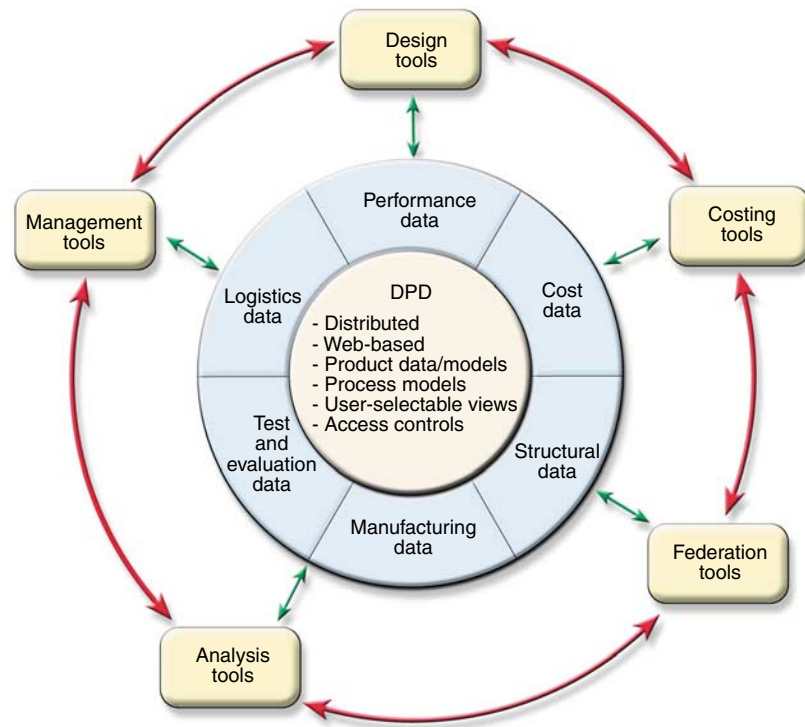
The evolving DoD JTA currently mandates the minimum set of standards and guidelines that are necessary to facilitate interoperability among systems that use information technology. As such, as the DoD JTA continues to mature, it is expected that many of the



standards specified in the JTA Document will apply to the development of new components within collaborative environments. For example, the information processing section of the JTA specifies explicit standards for data management services (Structured Query Language), document interchange (Hypertext Markup Language), and graphics interchange (Graphics Interchange Format). Other example mandates include the use of TCP/IP and UDP/IP for transport services, and the Defense Data Dictionary System for standard DoD terminology. In addition to mandates that apply to all DoD information systems, the JTA also specifies standards that apply only to specific domains. The standards defined in the M&S Annex to the JTA (such as the HLA standard) are expected to be especially important to SBA applications.

Data interchange formats (DIFs) is an area in which the need for new standards will be paramount, since the existence of such standards significantly enhances tool reuse and interoperability within and across collaborative environment boundaries. A DIF provides a common, intermediate format to facilitate the exchange of DPD information. DIFs are derived from a common data model that describes the semantics and syntax of shared data. These intermediate formats can be readily converted to any number of related output formats without loss or distortion of content using semi-automated, rapidly configurable parsing software. With an appropriate set of defined DIF standards, translators can be developed that allow different tool classes or implementations to consume relevant product information without manual translation. Tools with various internal product data formats can also use translators to generate and exchange product information with other tools or repositories via these same DIF standards. This concept is illustrated in Fig. 8.

Although broad standards for product data templates and associated DIFs are strongly needed by the acquisition community, there is much prior work that can be leveraged. For example, STEP (Standard for the Exchange of Product Model Data), CDIF (Common Data Interchange Format), and SEDRIS (Synthetic Environment Data Representation and Interchange Specification) all represent existing or emerging standards that may be pertinent to DPD development. In general, it is critically important for



**Figure 8.** Distributed product description (DPD) and data interchange formats (blue). Red arrows = tool-tool data exchange; green arrows = DPD-tool data exchange.

suitable representatives of the acquisition community (particularly in the M&S area) to become active participants in the development of standards relevant to acquisition programs and to ensure that these standards are appropriately reflected in the JTA. Other possible opportunities for standards to support acquisition include process models (e.g., test; verification, validation, and accreditation; security), HLA federation resources, and supporting databases.

## CONCLUSION

The road map produced by the Joint SBA Task Force has provided a starting point for DoD's implementation of SBA. Subsequent implementation planning, experiment efforts, and further definition of the architecture are all necessary to make the use of SBA a pervasive reality in the acquisition of future DoD systems. The top-level architecture concepts defined by APL during the road map development process have initiated the collaborative effort that must occur to gain consensus on the appropriate architecture implementation for SBA. Coupled with an acquisition process that can take advantage of these technical concepts and a culture that is amenable to the collaborative development of systems, this architecture can facilitate the achievement of the SBA vision of developing better DoD systems faster and with less total ownership cost.

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