# A Collaborative Environment Architecture for Future Combat Systems (FCS) Modeling and Simulation

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**ABSTRACT:** *This paper presents the architecture concept for a collaborative environment for the U.S. Army Future Combat Systems (FCS) program's modeling and simulation (M&S) activities. The FCS is being designed as part of the U.S. Army's Transformation effort to enable the Objective Force to perform a wide range of military operations, with innovative operational behaviors and flexible organizational structures. The acquisition strategy for the FCS program relies on applying a Simulation and Modeling for Acquisition, Requirements, and Training (SMART) approach to all aspects of the program.*

*The collaborative environment architecture provides a framework to facilitate and coordinate the use of M&S by both Government-authorized users and the contractor team during FCS design and development. The collaborative environment will include representations of the FCS design stored in the FCS Distributed Product Description (DPD). It will also include representations of Army and other DoD systems with which the FCS must interact, as well as representations of threat systems, the operating terrain and environmental conditions, and alternative scenarios to be simulated, all stored in an FCS Army/Industry Resource Repository (FAIRR).*

*The FCS DPD is a central architectural element in the collaborative environment. The DPD will maintain the system design information for alternative FCS platform designs and provide this information as needed for M&S analyses. The strong inter-networking capabilities of the FCS concept, along with the variety of innovative, coordinated operations to be conducted by FCS, place unusually stringent requirements upon the design of the FCS DPD. In particular, the DPD must maintain coordinated system design (structural) and behavioral (performance) views, must be able to incrementally reflect changed performance parameters in response to design changes, and must address the performance impacts on coordinated FCS operations due to changes in any one of the FCS platform designs (including the effects of combat damage or component failures). To respond to these requirements, an interface-centric approach has been advanced as the basis for the DPD logical design. This innovation is expected to provide significant advantages for representing an FCS compared to more traditional design approaches, which have typically emphasized either a product structure viewpoint or an M&S-oriented, performance characteristics viewpoint.*

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# 1. Future Combat Systems (FCS) Background

## 1.1 FCS Program Overview

The adaptive and unpredictable nature of future adversaries mandates that the Army have a rapid, decisive capability to respond across the full spectrum of operations. The Army's current capabilities clearly show a near-term strategic capabilities gap that impacts its ability to provide the National Command Authority (NCA) and Commanders In Chief (CINCS) the full range of land power options necessary to operate in this dynamic security environment.

On 12 October 1999, the Secretary of the Army and the Chief of Staff of the Army articulated a Vision designed to posture the Army to better meet the demands of the 21st Century. The Army Transformation Campaign Plan (TCP), initiated in December 1999, provides a roadmap that will translate this vision from concept to reality. The Objective Force is the goal of the Transformation. The Objective Force will have the lethality and survivability of current heavy forces and the deployability of light forces. The Army will equip Objective Force units with FCS, and will continue technological upgrades as new capabilities become available and required [1].

The FCS is a system of multi-functional systems that operates as a coordinated part of a distributed, networked force, enabling innovative operational behaviors and organizational structures. The FCS will enable the Objective Force to perform a wide range of military activities and operations, from small-scale contingencies to stability and support operations to major theaters of war. The FCS operates as part of a lightweight, overwhelmingly lethal, strategically deployable, self-sustaining, and survivable combat and combat support force.

The FCS leverages advanced technologies with the capability to incorporate future advances. This versatility will be realized through emphasis on an open architecture system concept, with an easily upgradeable and tailorable design approach to enable the system to engage in different missions as needed.

The FCS provides a secure command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) system to harness advances in the distribution and effective use of information power. The FCS also provides direct fire, indirect fire, air defense, non-lethal, and troop transport capability. The FCS may consist of a combination of manned and unmanned air and ground elements.

## 1.2 FCS Use of Modeling and Simulation (M&S)

The FCS acquisition program will incorporate a Simulation and Modeling for Acquisition, Requirements and Training (SMART) approach, which relies on M&S to facilitate more effective and efficient collaboration among functional discipline system stakeholders. SMART is the US Army's execution of Simulation Based Acquisition (SBA), and specifically seeks to collaborate with an industry Lead System Integrator (LSI) across the Army requirements, acquisition, and training communities. To this end, the government and the LSI will mutually develop and execute through an Advanced Collaborative Environment (ACE). The ACE is composed of the following five components:

- a government led and maintained Future Combat Collaborative Environment (FCCE);
- an LSI led and maintained Design, Engineering, Manufacturing Collaborative Environment (DEMCE);
- a Distributed Product Description (DPD);
- an FCS Army/Industry Resource Repository (FAIRR); and
- an Integrated Data Environment (IDE).

Since the SMART concept is fundamentally about an M&S facilitated, integrated approach to systems engineering, a key approach to integrating the analysis and test activities within the government is the application of a common analytic and evaluation taxonomy, referred to in this paper as the Weapon Systems Analysis Framework (WSAF). This taxonomy, developed by Dr. Paul H. Deitz of the U.S. Army Materiel Systems Analysis Activity (AMSAA) [2], parses the problem space of the FCS in accordance with four levels: Level 4 characterizes expected mission effectiveness for the FCS. Level 3 characterizes all expected functional capabilities needed to achieve mission success in Level 4. Level 2 characterizes all materiel components that make up the FCS, and that act to provide the needed functional capabilities in Level 3. Level 1 characterizes initial conditions and interactions between all components of the FCS as captured in Level 2, as well as those conditions and interactions with other non-FCS components (i.e., other blue systems and threat systems) and environments (i.e., terrain, weather, etc.). When this taxonomy is mapped to the systems engineering process and the logical data model of the DPD, it serves as the basis for enabling integrated analysis, test and evaluation, and modeling and simulation application. The combined concepts of the taxonomy, systems engineering process, and DPD, are referred to as the Test, Analysis, Modeling and Simulation (TAMS) Construct. The WSAF and the TAMS Construct are discussed further in Section 3.

## 2. Review of SBA Architecture Concepts

### 2.1 Overview

In March 1998, after defining a top-level vision and goals for SBA, the Acquisition Council of the DoD Executive Council for Modeling and Simulation (EXCIMS) established a Joint SBA Task Force to develop a roadmap for DoD's SBA implementation. Over a six-month study period and a three-month review period, the Task Force developed a notional architecture for SBA and a roadmap of recommended actions to implement SBA in DoD, both of which were documented in the Task Force's report in December 1998 [3]. Several of the architectural concepts used in the definition of the FCS collaborative environment architecture draw upon heritage from the SBA Road Map effort. Five principal SBA architectural concepts were proposed:

- Collaborative Environments (CEs);
- a Collaborative Environment Reference Systems Architecture (CERSA);
- Distributed Product Descriptions (DPDs);
- a DoD/Industry Resource Repository (DIRR); and
- Data Interchange Formats (DIFs).

Two of these concepts, the CE concept itself and the DPD structure, have been adopted directly in the FCS M&S CE architecture, and are described in the following subsections. A third, the DIRR, has been adapted to form a similar FCS-specific repository concept, and the use of appropriate DIFs is assumed for data exchange.

### 2.2 Collaborative Environments (CEs)

The term "collaborative environment" was defined in [3], in the context of SBA, as "an enduring collection of subject matter experts (SMEs) supported by interoperable tools and data bases, authoritative information resources, and product/process models that are focused on a common domain or set of problems." The collaborative environment concept has also been adopted by the U.S. Army SMART initiative as a means of providing for continuous collaboration among all stakeholders. The Joint Strike Fighter (JSF) program has also adopted the CE concept as the basis for its Strike Warfare Collaborative Environment (SWCE) [4].

### 2.3 Distributed Product Descriptions (DPDs)

As defined in [3], a DPD is "a distributed collection of digital product-centric information that is interconnected via web technology into what appears (to the user) to be a single, logically unified product representation." The purpose of a DPD is to provide a common reference for all stakeholders involved in the life cycle of a product. Standards for the exchange of DPD information among the participants in an acquisition program are particularly important. Figure 1, adapted from [3], shows the concept for the use of DPDs and DIFs with tools utilized by various functional disciplines in acquisition programs.

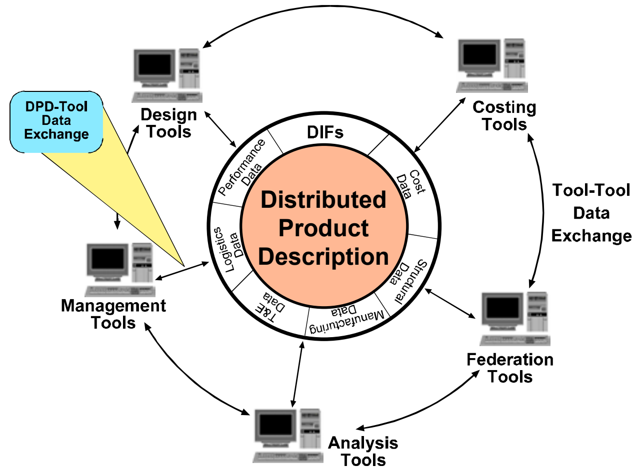


**Figure 1. Relationships among DPDs, DIFs and tools (adapted from the SBA Road Map) [3]**

Within its CE concept, the JSF program has also adopted the concept of a DPD. A description of the intended JSF implementation can be found in [5].

## 3. FCS Collaborative Environment Design Overview

### 3.1 Context for the FCS Collaborative Environment

The FCS-focused operational environment can be thought of as being "nested" within a larger operational environment that includes representations of other Army Objective Force systems with which the FCS must interact. Similarly, this Army-focused operational environment must be nested within a larger Joint operational environment that represents all other systems with which Army systems must interact. This relationship is depicted graphically in Figure 2, drawn from [6].

In parallel with the FCS collaborative environment definition, it is anticipated that an M&S capability will be developed for the Objective Force, which is likely to include at least several M&S tools and facilities that are also applicable to M&S of the FCS. The FCS collaborative environment definition will need to be cognizant of such Objective Force M&S capabilities as they are developed.

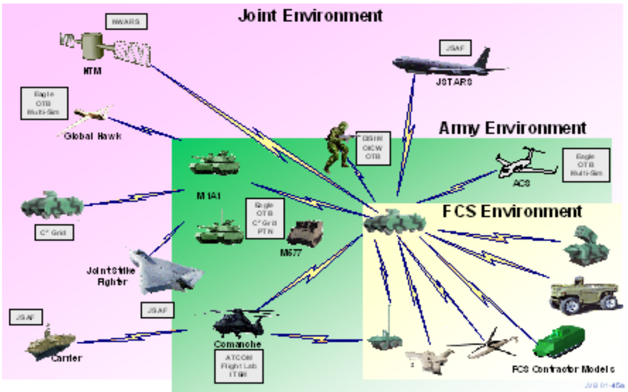


**Figure 2. Army and Joint Context for FCS Collaborative Environments**

Within the TAMS Construct, the WSAF framework provides four levels of abstract spaces, with operators acting as processes between adjacent levels that transform vectors in each space to vectors in the next higher space. Starting from initial conditions, the vectors in the levels, numbered from 1 to 4, represent initial conditions and damage encounters (Level 1), component conditions (Level 2), functional capabilities (Level 3), and military utility (Level 4). The framework was originated to represent platforms but may be extended to a system-of-systems through "combined levels" numbered 2 through 4. A depiction of the framework for both individual platforms and a system of systems, adapted from [2], is shown in Figure 3.[1] In order to support the FCS TAMS Construct, the FCS collaborative environment needs to be aligned with and to support this WSAF structure.

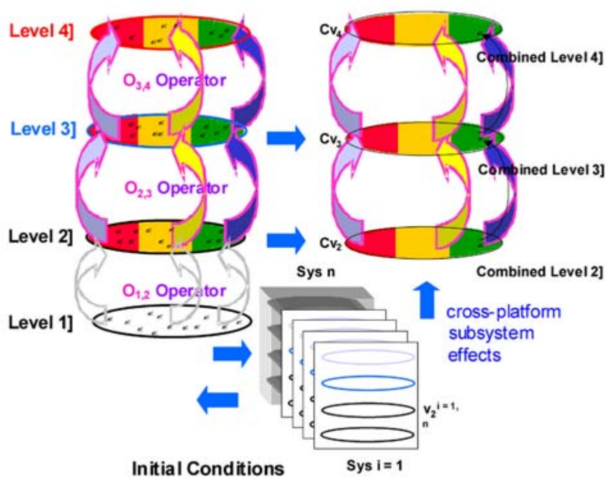


**Figure 3. Depiction of the Weapon Systems Analysis Framework for a Platform and a System of Systems**

[1] The trailing brackets in Figure 3 reflect a stylistic convention used in Reference [2].

### 3.2 FCS Collaborative Environment Purposes and Focus Areas

As noted in [7], all activities associated with the FCS program will be in some way shaped by the application of M&S. To execute within the cost and schedule constraints, application of M&S will serve to enable:

- robust systems engineering (to include credible analytic support and test and evaluation (T&E));
- a robust, responsive feedback loop between the contractor and government organizations involved in requirements analysis, design synthesis, and system verification;
- robust design maturation, and continuous technology upgrade insertion;
- training simulation development leveraged from system development such that training capability is fielded simultaneously with the system; and
- continuous Total Ownership Cost (TOC) analysis such that changes in design can be assessed for TOC implications.

Additionally, M&S efforts will be leveraged to support multiple applications both for FCS and Objective Force development activities. In early 2001, the FCS program established an overall framework for its M&S environment that envisioned as one of its primary components the Future Combat Collaborative Environment (FCCE). The FCCE has been defined as the M&S collaborative environment serving Government FCS stakeholders. The first step in the design of a collaborative environment should be the definition of the purposes for which it will be used. These purposes will drive the M&S tools selected, the stakeholders and SMEs that will be involved in its use, and the processes employed for its management.

### 3.3 FCS Collaborative Environment Top-Level Design

This section provides an overview of the top-level design of the FCS collaborative environment. As noted in section 2.1, several of the constructs have been derived from work reported upon in [3]. The specific top-level design shown here is as documented in Annex F of the DARPA/Army FCS Program Solicitation [8]. Some descriptive information of the various components has been taken from [9].

The FCS enterprise supporting the FCS acquisition program will be managed and executed within the context of the FCS ACE, which consists of five principal components indicated earlier in Section 1.2. The FCS ACE is illustrated in Figure 4. The ACE components, each with their respective information management

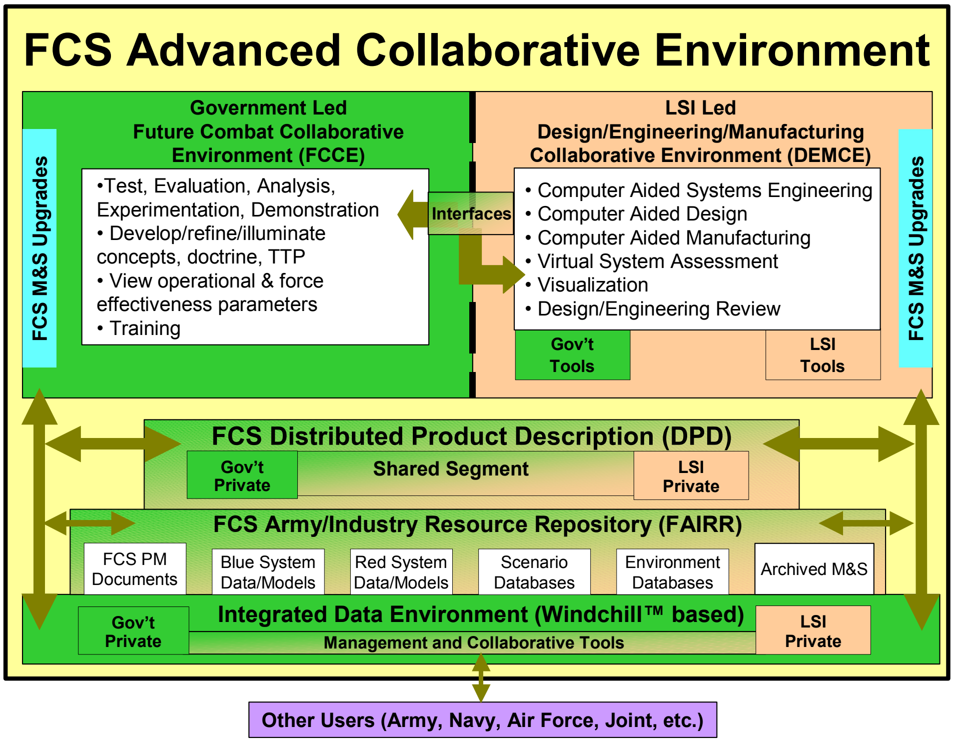


**Figure 4. Top-level view of the FCS collaborative environment architecture.**

systems and applications, will be managed by the respective stakeholders (i.e., Program Office, LSI, and other Government FCS program support organizations).

There are two principal "layers" of the FCS collaborative environment architecture: the M&S tools layer and the resources layer.

The M&S tools layer of the FCS M&S architecture is depicted in Figure 5 using a view slightly altered from Figure 4. The FCCE M&S tools consist of three classes of models and simulations (modeling tools, simulations, and simulation federations), collectively referred to as the FCCE Suite of M&S, and tools for management and collaboration.

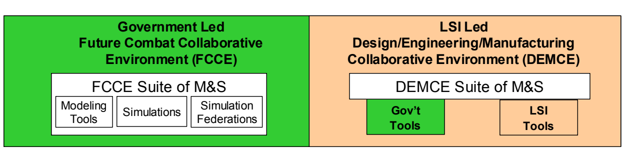


**Figure 5. A view of the M&S tools layer of the architecture.**

The LSI will lead the establishment of the DEMCE (mutually with the Government) to support concept development, architecture development, system design, integration, engineering, functional analysis, test and evaluation, manufacture, training, life-cycle processes, etc. The LSI will populate the DEMCE with a set of M&S tools that support these activities. As shown in Figure 5, both Government-provided tools and LSI-provided tools will exist within the DEMCE.

The resources layer of the FCCE and the DEMCE is designed to include all of the information needed as input by the tools in the ACE, archived results from the execution of the M&S tools, and any FCS-related documentation needed by the various FCS stakeholders. User access to information stored in the resources layer is provided via the FCS IDE. There are two key constructs in the resources layer: the DPD and the FAIRR. As the DPD is discussed in detail in section 4, only a brief overview is presented here.

The FCS DPD is designed to be the repository for all authoritative information on the FCS needed as input by the tools in the tools layer of the FCCE and the DEMCE. A top-level view of the DPD, extracted from Figure 4, is shown in Figure 6 for ease of reference.

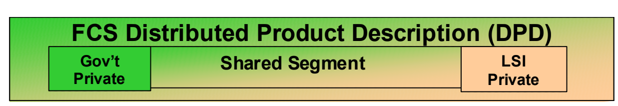


**Figure 6. Top-level view of the FCS Distributed Product Description.**

As the name implies, the FCS DPD is designed to be a physically distributed (but logically unified) repository of

FCS-specific information. Most information stored in the DPD is expected to be in the form of data. However, if the most authoritative representation of some aspect of the FCS cannot be described by data alone, the DPD will need to include a model for that aspect. Three types of segments are included in the design:

- an LSI Private segment,
- a Government Private segment, and
- a shared segment.

Each DPD segment will need to have both unclassified and classified areas, as required.

The DPD and its various segments will be made available to authorized users (in the FCS, Army, and Joint communities) using the FCS IDE. Access controls on the individual private DPD segments will be used to provide selective access only to users with a need for the information. The Government will establish an IDE for the program management office based on Windchill™. The LSI will develop its IDE, as well as the interfaces to the government IDE, to permit access to program information.

### 3.4 The FCS Army/Industry Resource Repository

In addition to accessing FCS-specific information stored in the DPD, the models and simulations in the FCCE toolset (as well as many models and simulations in the DEMCE toolset) will need to be able to access authoritative non-FCS information. This information may be divided into four basic categories:

- representations of friendly (blue) systems (including platforms, weapons, etc.),
- representations of threat (red) systems (including platforms, weapons, etc.),
- scenario information, and
- environmental information.

Each of these categories of information must be stored in a digital form that can be readily translated for use by the various tools. A logically unified (but physically distributed) repository structure provides a single source of this authoritative non-FCS information, referred to as the FCS Army/Industry Resource Repository (FAIRR). A top-level view of the FAIRR, extracted from Figure 4, is shown in Figure 7 for ease of reference.

Text FCS program management documents are also resources for FCS, which will be stored in the FAIRR. Archived M&S results (which are outputs of, rather than inputs to, M&S tools) represent a special class of information in the FAIRR that is discussed in the next section.

The FAIRR capability, which is certainly of direct benefit to the FCS, would also benefit many other Army programs and activities. As such, creation of the FAIRR represents an opportunity for Army enterprise-level collaboration in M&S. Developing such a capability, however, is likely to require an extended effort over a number of years, both to find authoritative sources for the required information and to develop the technical capabilities of the repository itself. To achieve the desired capabilities, a list of potential evolutionary design and implementation steps has been developed, categorized into near-term, mid-term, and long-term time frames. This list is presented in Table 1.

### 3.5 Archived M&S Results and the "Boxed Set" Concept

As various analyses are conducted over time, significant volumes of M&S results will be created, both by authorized Government users of the FCCE and by LSI users of tools in the DEMCE. Although not every output of every model or simulation execution will produce results that need to be saved, there are likely to be significant technical studies done that will be used as a basis for major design and/or acquisition decisions. In order to preserve these results for subsequent reference, and for potential reconstruction or re-execution with modifications, provision has been made for configuration-managed *archived M&S results* in the collaborative environment architecture. The responsibility for archiving M&S results produced in the FCCE will lie with the authorized users of the various tools, under the overall authority of the FCS program office. The LSI should be responsible for archiving its key M&S results, with the FCS program office being able to review these results in a manner sufficient to retain technical insight into the LSI designs.

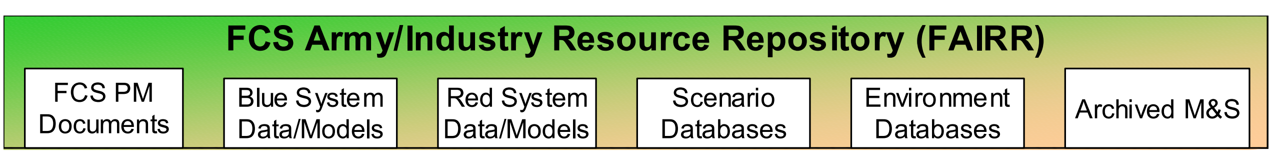


**Figure 7. Top-Level View of the FCS Army/Industry Resource Repository**

**Table 1. Potential FAIRR Evolutionary Design and Implementation Steps.**

| Time Frame | Steps to Implement Desired Capabilities |
|---|---|
| **Near-term** | Collect information from available sources, structured for input into key FCCE M&S tools |
| | Begin development of data schema to ensure consistent semantic representations for data elements used by components of the M&S toolset |
| **Mid-term** | Develop application-neutral data representations for all data elements |
| | Develop metadata for sources of authority; verification, validation, and accreditation (VV&A) information; etc. |
| | Develop data interchange formats (DIFs) for various data types—leverage existing standards (e.g., Extensible Markup Language [XML]; SEDRIS for environment data) wherever possible |
| | Incorporate version management and archival capabilities |
| | Incorporate consistency checking—document relationships among related elements; perform automatic calculations where possible |
| | Develop translators to automatically extract and format inputs for M&S toolset components |
| **Long-term** | Develop automated electronic linkages to individual and consolidated sources of authoritative information wherever possible |
| | Develop automatic change notification process via electronic mail to registered users of specific information |
| | Develop subscription service for pre-defined sets of information for individual users and M&S toolset components |

Related to the provision for archived M&S results is the concept of a *boxed set*, derived from a similar concept generated for the JSF program [4]. A boxed set may be thought of as a documented instance of use of the ACE involving execution of a component of the M&S suite, using information drawn from the FCS DPD and the FAIRR that produces an archived M&S result. The boxed set itself consists of:

- the M&S tool itself, with its version explicitly identified for configuration management purposes;
- the FCS DPD inputs used by the M&S tool during the particular (set of) execution(s);
- the FAIRR inputs used by M&S tool during the particular (set of) execution(s);
- other execution-specific M&S tool input information;
- the outputs from the M&S tool execution, including any post-processed results; and
- other configuration information (e.g., computer(s), operating system(s), points of contact).

The boxed set information for the particular (set of) execution(s) is saved in the archived M&S results area of the FAIRR. Where an M&S tool is one under configuration management by an M&S proponent that archives all versions of the M&S tool, only version identification information for the tool needs to be saved. This process is illustrated for the use of an M&S tool in the FCCE in Figure 8.

## 4. The FCS Distributed Product Description

### 4.1 DPD Scope and Overview

A DPD, as illustrated earlier in Figure 4, is at the heart of the architecture for the FCS Advanced Collaborative Environment. As described in Section 3, the FCS DPD is designed to be the repository for all authoritative information concerning the FCS that may be needed as an input by the tools in the tools layer of the FCCE or the DEMCE.

As Figure 9 illustrates, the data in the DPD are intended to support modeling at all levels, from campaign modeling (at the highest level of aggregation) to system and subsystem modeling (at the engineering level). The DPD contents will primarily address the design of an FCS platform, and must represent the basic systems and subsystems within an FCS. The DPD will not typically or contain information for the basic models of physics or fundamental technologies, as depicted at the base of the triangle in Figure 9. These will often be employed externally to the DPD.

Models and simulations will draw upon the fundamental engineering characteristics data in the DPD in order to estimate FCS performance parameters, which are then entered back into the DPD for use in M&S at the next higher level of aggregation.

In order to properly represent FCS capabilities within mission and campaign models, the DPD must be able to describe how an FCS unit communicates with and coordinates action with other types of Army and Joint units and platforms, as well as how the FCS unit (itself) performs. As a result, the DPD must be able to *simultaneously* maintain both a performance-oriented view and a physically-oriented view (i.e., an assembly decomposition). The performance characteristics of an FCS are most closely associated with its major

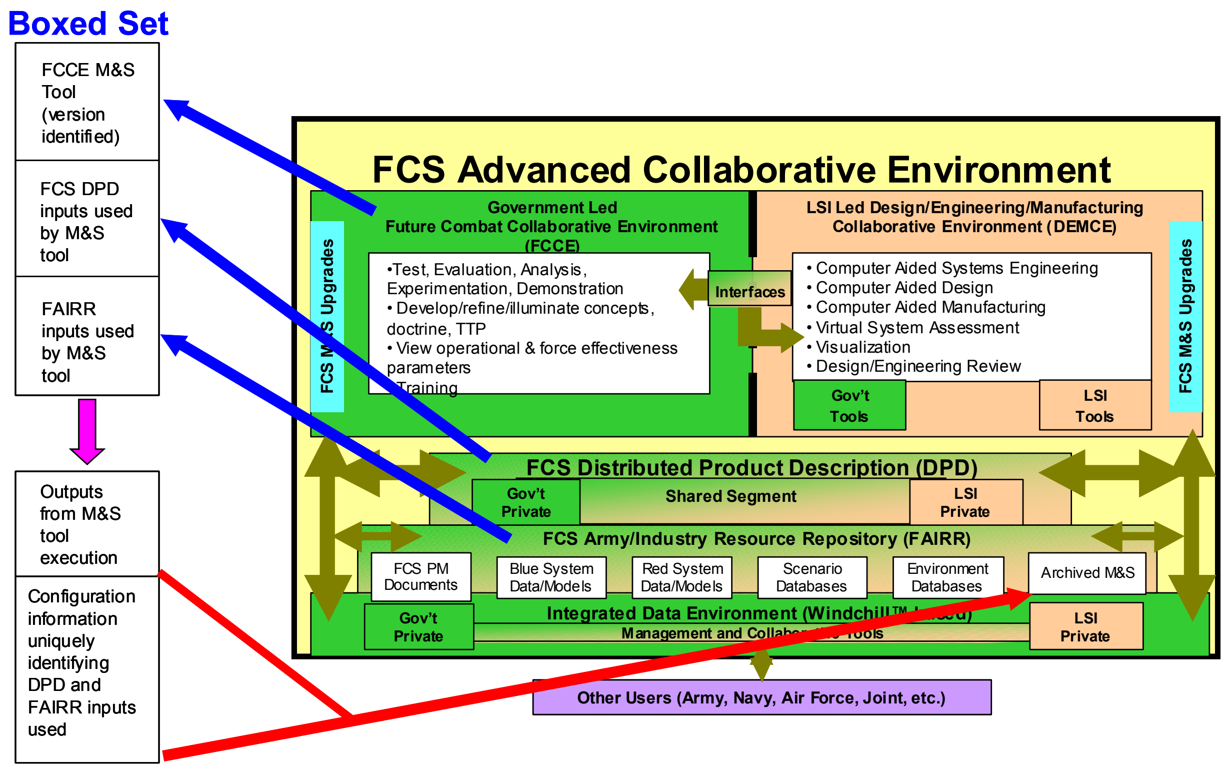


**Figure 8. Illustration of use of a "boxed set" for M&S execution.**

subsystems. Figure 10 illustrates this duality of viewpoints for an FCS platform, which can be viewed as being composed of either assemblies/sub-assemblies (on the Physical View side) or subsystems, including their behavior (on the Performance View side). Both of these viewpoints exist at the same time, and must remain consistent with each other.

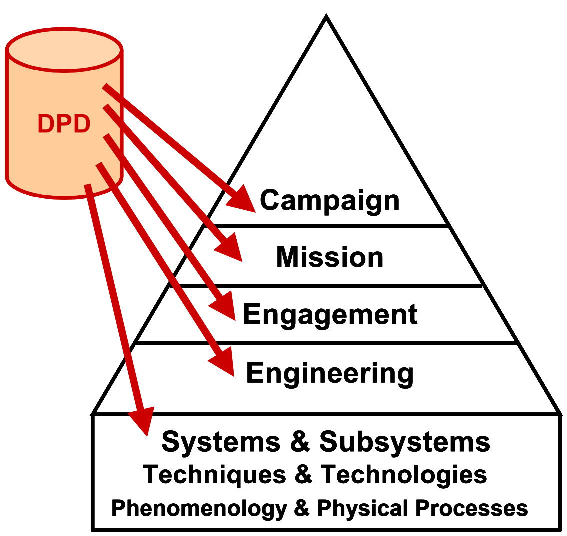


**Figure 9. M&S Hierarchy**

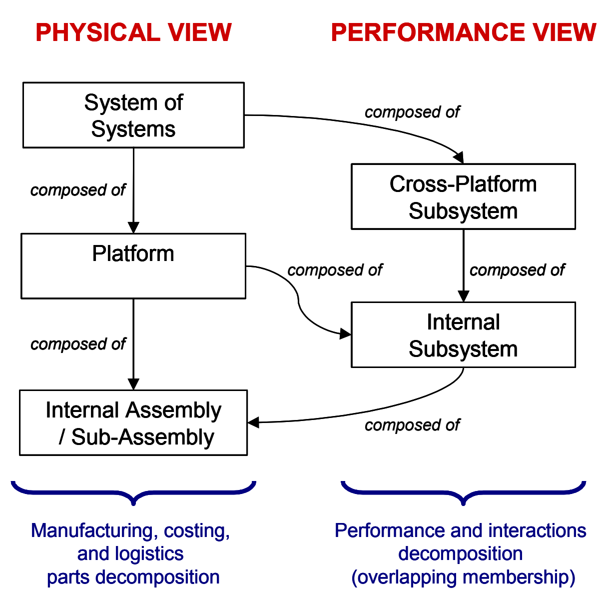


**Figure 10. System Decomposition Structures**

A system-of-systems is composed of different platforms that operate together to perform some mission, but the members may vary from mission to mission, or even over time as a mission progresses. A cross-platform FCS subsystem results from the coordination of actions by related subsystems on different FCS platforms, enabling

FCS platforms to interoperate to achieve system-of-systems performance.

The relationships shown between the boxes in Figure 10 reflect fundamental FCS characteristics that are inherent in the nature of any FCS system. The FCS DPD must be able to represent all these types of system elements and relationships.

**4.2 DPD Support for Weapon Systems Analysis**

To support the WSAF, as illustrated in Figure 3, different types of M&S are applied to effect the transitions from one level of analysis to the next higher level. Traversing upward through levels on the left side of the illustration is equivalent to addressing the lower tiers of the M&S hierarchy, as shown in Figure 10, while traversing the combined levels on the right side of the illustration to reach Combined Level 4 is equivalent to addressing the upper tiers of the M&S hierarchy. As Figure 3 illustrates, there has to be a cutover of information between Level 2 and Level 3 so that the MOEs can be determined by exercising multi-unit and force-on-force models.

Both the FCS collaborative environment architecture and the DPD design must be aligned to accomplish the computations necessary for the WSAF. The ovals in Figure 3 indicate collections of data that are stored in the DPD, except for the Level 4 and Combined Level 4 data, which are instead recorded in the Archived M&S Results element of the FCS ACE. This is because the DPD is intended to address only the characteristics of the platform(s) being designed, while the Level 4 results depend on (1) the interactions between that platform(s) and other blue and red systems, and (2) the environmental conditions in which those interactions take place. Table 2 provides a "capsule summary" of the WSAF levels by suggesting a key question that should be answered by the data at each level.

The WSAF analysis process begins with the enumeration of a set of initial conditions, as illustrated at the bottom of Figure 3. One challenge in defining the Initial Conditions data is to fully enumerate and record the following:

- potential technology options;
- subsystem design alternatives to implement these technologies;
- design constraints that limit which subsystems can be implemented together;
- capabilities for interactions among subsystems within multiple systems in the design space (i.e., cross-platform subsystem effects); and
- component and subsystem co-dependencies.

**Table 2. Key Questions for WSAF Levels**

| | **Standalone Unit** | **Cooperating Units** |
|---|---|---|
| **Level 4** | What MOEs can be achieved by a platform in different operational contexts? | What MOEs can be produced by a system-of-systems, acting within a larger force? |
| **Level 3** | What MOPs can be produced by damaged and undamaged platforms? | What MOPs can be produced by multiple platforms acting as a system-of-systems? |
| **Level 2** | How do different types of component damage or failure affect functionality? | How do platform damage conditions affect platform interactions? |
| **Level 1** | What types of platform damage will be sustained from destructive encounters? | How do different destructive forces damage the means of interaction among platforms? |
| **Initial Conditions** | What technologies and components are available; how can they be combined? | How can multiple platforms interact, depending on the components used? |

Based on this initial set of options and constraints, a table of system alternatives is constructed to establish the basic Level 1 data. Level 1 data also include the potential "encounter vectors" that each system alternative might undergo in combat or other use that can damage one or more components in the system. This information is used to calculate the Level 1 to Level 2 transition.

Different encounter vectors applied to *each* Level 1 configuration create, as a result, a set of Level 2 alternative conditions, or "states" of damage. They may vary from event to event and among platforms of the same type for any one type of damage encounter, so damage state transitions are inherently stochastic.

The DPD Data Structure must support the derivation of dependency/traceability linkages due to damage or failure. These linkages are traced from:

- component damage/failure status changes, to …
- interactions eliminated, then to …
- states/modes no longer supported, then to …
- combat processes affected, and finally to …
- MOP/MOE changes.

By applying engineering system models and simulations, Level 3 results can be computed to show the MOPs that can be achieved under normal operating conditions, or subsequent to different types of damage encounters, or in different operating environments.

Finally, the individual and combined Level 4 MOEs can be computed from the Level 3 MOPs. This involves the combination of data from the DPD and the FAIRR for each different scenario being analyzed. The M&S outputs and the resulting individual platform and combined MOEs are recorded in the Archived M&S Results element of the FCCE.

### 4.3 An Approach to a DPD Logical Data Model

A logical model is an organized layout of the subject matter content for a database or repository, independent of the implementation technique. It includes at a minimum the data attributes associated with each "subject" concept (i.e., entity, object, table, etc.), and the constraints (i.e., relationships) that govern the entry of data values within each "subject".

The DPD logical model design approach should be top-down, and should expand from a carefully prepared "core" structure that serves as a governing framework. The core structure should be based upon fundamental and very general system principles in order to be able to accommodate future FCS designs that may not have been conceived at the time the DPD is initially established.

The remainder of this section identifies key systems principles that should drive the design of the core DPD logical model, and describes how they may be incorporated.[2] A very simple graphical notation is used in this section for diagramming the high-level logical model:

- A modeling concept (e.g., an "object", or, in older modeling notations, an entity) is represented by a rectangle.
- The name for the concept is within the rectangle.
- A "relationship" that establishes some linkage between two concepts is indicated by an arrow.
- The label adjacent to the arrow indicates the purpose or motivation for establishing the relationship.
- The direction of the arrow indicates which way to "read" (interpret) the relationship label.

Using this notation, Figure 11 illustrates a logical model for the pattern of concepts and relationships represented in Figure 10.

[2] *Acknowledgement:* Figures 11 through 14 and the accompanying description have been adapted from the work in process for IEEE project P1175 (preparing the replacement for IEEE Standard 1175-1992), and reflect the collaborative efforts of the working group members.

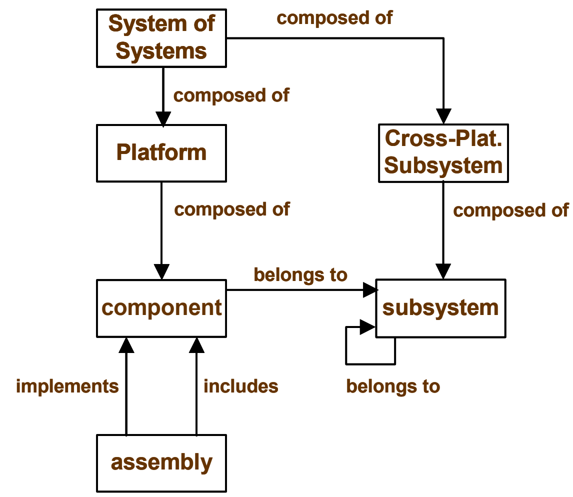


**Figure 11. Identifying System Decomposition Structures**

The essential characteristic of any useful military system is that it produces outputs that have some direct intended impact on the system's environment (e.g., emit some form of material or energy to damage something), or permit some cooperative interaction with friendly units. Always, something must be taken in as an input in order for a system to be able to produce an output. Collectively, a system's inputs and outputs are called its interactions. An interaction may be composed of some combination of energy or material. Sometimes this energy or material also serves as a carrier of information. If so, the information content conveyed is also recognized as a distinct form of interaction. As needed, an interaction can be decomposed based on either the time separation or the spatial separation (or both) of any "smaller" interactions within an interaction. For electronic signal processing analysis, a frequency-based decomposition of interactions may be used in lieu of a time-based decomposition.

A basic systems analysis principle is that any system must have an identifiable boundary to determine what is "in" and what is "out" of scope for a design analysis. Interactions may be absorbed or emitted from some point or area on that boundary, which is called a port. A port can be the entire system boundary, as is the case, for example, when the interaction of interest is a thermal signature. Ports need to be identified in the DPD in order to provide traceability between the system itself and its interactions. Figure 12 depicts this pattern of input/output relationships, which must be represented within the DPD.

Describing the behavior of a system means identifying which actions can take place within each system state, and which state-transitions correspond to each action. In some cases, completing an action is dependent upon some other input or resource being available. This situation is called an obligation, which may require the transmission of a request for the missing resource to be sent to another system that is able to supply it. When the response is received, making the resource item available, the action can complete. For example, a repair may require a spare part (an obligation). To get the part shipped in from a warehouse (the response), a requisition (the request) must first be sent out. Figure 13 illustrates these relationships.

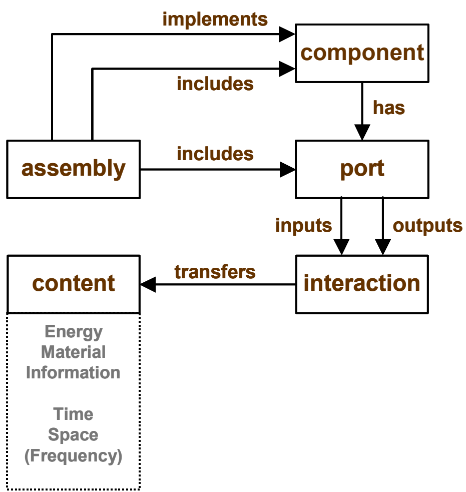


**Figure 12. Linking System Interactions with System Physical Structures**

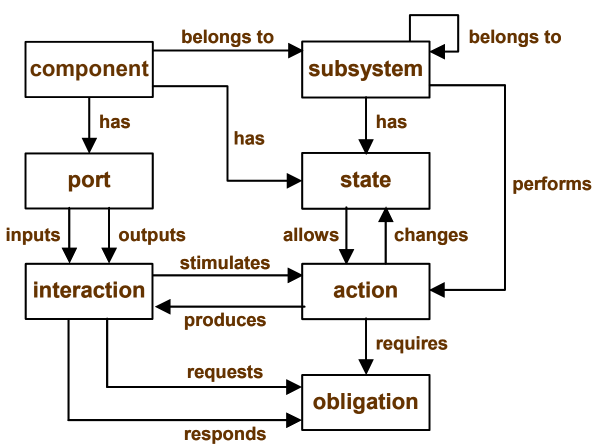


**Figure 13. Linking Components and Subsystems to System Behavior**

Table 2 shows the combined list of the high-level concepts contained within the previous three figures. These concepts and relationships can serve as the basis for a database implementation to create an initial DPD structure. If a relational database management system (DBMS) were employed, each concept in Table 3 would typically correspond to a database table.

**Table 3. Distributed Product Description Concept Partitioning**

| Viewpoint | DPD Model Concept |
|---|---|
| **Physical View**<br>*(system structural elements)* | Assembly<br>Content |
| **Interface View**<br>*(system elements closely related to system inputs and outputs)* | System of Systems<br>Platform<br>Component<br>Port<br>Interaction |
| **Performance View**<br>*(system behavioral characteristics)* | Cross-platform subsystem<br>Subsystem<br>State<br>Action<br>Obligation |

An examination of the relationships between the concepts shows that none of the Performance View concepts have any direct relationship linkages, within the DPD logical model, to any of the Physical View concepts. However, as illustrated in Figure 14, the Interface View provides a "bridge" for relating performance characteristics to the physical design features, permitting derived (or inferred) relationships between the Performance View and Physical View concepts are depicted by the dashed line.

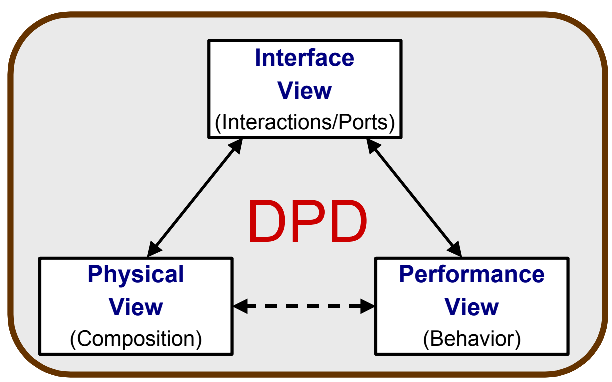


**Figure 14. Distributed Product Description Logical Views**

The pattern of relationships depicted in Figure 14 is intentional, and is a key feature of this logical structure. The discipline provided by the Interface View elements helps ensure that any discrepancies between the Physical View and the Performance View can be detected, verified, and ultimately resolved. By virtue of its central positioning, the Interface View offers an appropriate point for attaching FCS requirements, and thereby helps to ensure consistency between structural requirements and behavioral requirements.

## 5. Summary

Beginning from the roots of the collaborative environment concept within the evolution of SBA, this paper has presented an architecture for the FCS ACE, a collaborative environment that responds to the particular needs of the FCS program. Included in the architecture is a DPD, a distributed repository of data describing the FCS, and a FAIRR, a distributed repository of data concerning the operational environment of an FCS platform. The paper has also described the use of M&S within the ACE, including the role of M&S and the DPD in support of the WSAF, and has elaborated the principles for developing a DPD as a central element of the ACE.

## References


[1] TRADOC Pamphlet 525-3-91, The United States Army Objective Force Tactical Operational and Organizational Concept for Maneuver Units of Action. Draft, Dated 6 November 2001.

[2] P. H. Deitz, J. Sheehan, B. Harris, and A. B. H. Wong, "A General Framework and Methodology for Analyzing Weapon Systems Effectiveness," in Proc., Second Biennial National forum on Weapon Systems Effectiveness, March 27-29, 2001, Laurel, MD.

[3] *A Roadmap for Simulation Based Acquisition – Report of the Joint Simulation Based Acquisition Task Force*, Acquisition Council Draft for Coordination, December 4, 1998.

[4] J. E. Coolahan, F. T. Case, and R. J. Hartnett, Jr., "The Joint Strike Fighter (JSF) Strike Warfare Collaborative Environment (SWCE)," 2000 Fall Simulation Interoperability Workshop, September 17-22, 2000, Orlando, FL.

[5] J. W. Hollenbach and R. J. Hartnett, Jr., "The Joint Strike Fighter (JSF) Distributed Product Description (DPD)," 2000 Fall Simulation Interoperability Workshop, September 17-22, 2000, Orlando, FL.

[6] V. Bettencourt, "Objective Force M&S," Tenth Annual Executive Forum on Modeling and Simulation, May 29-31, 2001, Vienna, VA.

[7] *Simulation Support Plan, Future Combat Systems*, Future Combat Systems Program Office, Draft, November 2001.

[8] Defense Advanced Research Projects Agency (DARPA) Solicitation No. PS 02-07, "DARPA / Army Future Combat systems Program Solicitation," November, 2001.

[9] JHU/APL Report JWR-01-030, *Future Combat Systems (FCS) Modeling and Simulation (M&S) Collaborative Environment Design Definition Final Report*, November 9, 2001.


## Author Biographies

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