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CAPABILITY-BASED MODELING METHODOLOGY: A FLEET-FIRST APPROACH TO ARCHITECTURE

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WARFARE SYSTEMS DEPARTMENT

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FOREWORD

This paper describes a Fleet-first methodology to generate Data Model 2-compliant architectures and use them to improve strategic and tactical readiness. Architectural design originates with mapping key capabilities to desired effects articulated by identified operational stakeholders, which lends the methodology to a Fleet-first perspective versus a system- or technology-first perspective. Capability-Based Modeling Methodology identifies best practices for executing development of a "Fleet-first" architecture, and explains how each core model aids in managing specified data types and relationships. The paper concludes by discussing impacts on mission engineering from following a Fleet-first methodology.

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GLOSSARY

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CBMM	Capability-Based Modeling Methodology
CV	capability viewpoint
DoD	Department of Defense
DODAF	DoD Architecture Framework
DODI	DoD Instruction
DON	Department of the Navy
DOTMLPF	doctrine, organization, training, material, leadership, personnel, and facility
DRM	Design Reference Mission
I&I	integration and interoperability
ICF	Integrated Capability Framework
ISR	intelligence, surveillance, and reconnaissance
M&S	modeling and simulation
NTA	Navy tactical tasks
OV	operational viewpoint
SAG	surface action group
SYSCOM	Systems Command

1.0   BACKGROUND

Architectures have been recognized as useful for managing the complex relationships among differing data types dating back to the development of the original Zachman framework, first proposed by John Zachman in 1982 for automating system design. Within two decades, the Department of Defense (DoD) had made progress toward integrating architectures into defense acquisition processes to aid in better Joint system designs. Problems with integration and interoperability (I&I) have flourished with the sharp rise in technological complexity of warfare systems acquired, deployed, and used throughout the Fleet, yet the use of architectural design tools and processes have been slow to evolve. The DoD has reacted to these issues by establishing updated DoD-wide acquisition guidance and creating organizations responsible for defining I&I processes. To adequately execute these I&I processes a new, Fleet-first architectural methodology is required to aid in consolidating data and data needs across a diverse group of Joint and coalition stakeholders.

The Capability-Based Modeling Methodology (CBMM) was developed through multiple architectural efforts to document how the Fleet conducts naval operations and how it uses available systems and/or services to achieve a stated desired effect. By using the CBMM approach to building mission architectures, architects can increase the efficiency at which they organize, scope, and investigate current I&I issues. This approach also creates a mechanism that encourages the utility and reuse of architecture tools and products throughout the mission engineering and acquisition management process. CBMM development originated in the Navy enterprise but is intended for application in both Joint and coalition organizations.

1.1   Mission Engineering

Mission engineering involves planning, analyzing, organizing, and integrating emerging operational concepts to specify the end-to-end mission architecture attributes across the doctrine, organization, training, material, leadership, personnel, and facility (DOTMLPF) spectrum. These mission architectures inform the communities of interest involved in fulfilling mission needs statements, and aid in identifying how material and non-material entities contribute to Fleet readiness.

To achieve the stated objectives of mission engineering, a significant amount of data must be identified, collected, analyzed, and updated. Data identification requires engineers understand the causes and effects contributing to the achievement of the Fleet's desired effect for a specified mission area. Data collection is the activity associated with learning and understanding how a desired effect is achieved. Data analysis is the process of investigating potential problems or inefficiencies experienced by the Fleet while operating toward its desired effect. Updating data is the process of applying lessons learned to the Fleet enterprise, whether it be for evolving the material or non-material understanding of the mission. Each of these activities requires vast amounts of information and a comprehensive understanding of how each data element relates to another. Data identification, collection, and analysis are necessary activities and processes for assessment of developed capabilities and evaluation of desired capabilities that are fundamental to achieving the objectives of mission engineering. Figure 1 illustrates this concept.
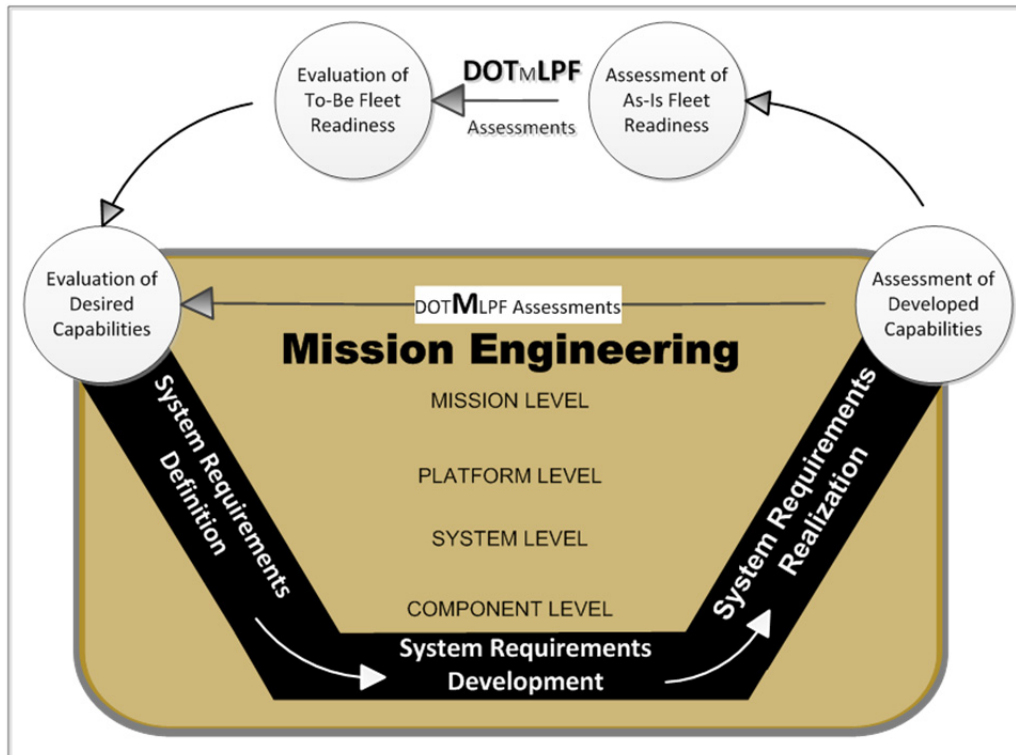
Figure 1: Conceptualizing Mission Engineering and its Relationships to DOTMLPF Requirements

This data management requirement is the key purpose of architecture, dating back to its inception. Current Department of Defense Architecture Framework (DoDAF) instruction identifies a data model and how dozens of architecture viewpoints may be used to manage the identified data relationships. Because of DoDAF's wide appeal to an organization as diverse as the DoD, it does not specify particular approaches for developing or tailoring architectures toward a particular use, such as modeling Fleet operations. Though several prominent architectural methodologies exist, none specifically address how architectures may be used to adequately manage data required to investigate Fleet operations and readiness.

1.2   Mission Architecture

The Navy, as well as the DoD as a whole, faces numerous issues today regarding problems in system integration throughout the Fleet and interoperability among deployed technologies. Problems also exist with the maturation and development of training, doctrine, and policies taken toward current and emerging threats. Combined, these deficiencies represent causation for degraded Fleet readiness against present and future threats. These problems, particularly those associated with Fleet acquisitions, are mitigated in part by responsible systems engineering practices and by new regulations established to guide system development and integration with the current Fleet. Still, the quantity and quality of data that systems engineers and Fleet advocates are confronted with becomes difficult to manage without using a data management tool such as an architecture. When built for this purpose, the architecture becomes otherwise known as a mission architecture.

Mission architecture continues to become an increasingly recognized role in system development and acquisition. CBMM development was initiated as a result of ongoing Navy

efforts to evolve current acquisition practices and solve problems in requirements definition and system development that often result in inefficient I&I.

CBMM focuses on a Fleet-first approach, meaning it specifies architectures must begin from the Fleet's needs and desired outcomes to a specific mission or strategic operation. Relationships between tasks and systems are drawn in context of a single or set of capabilities that allows senior leadership to understand which systems are being used to support essential tasks that contribute to a specific desired effect. These relationships provide a vehicle for analysis of current and future Fleet issues that threaten warfighters' state of readiness.

1.3   DODI5000.02

Department of Defense Instruction (DoDI) 5000.02, "Operation of the Defense Acquisition System," is a policy endorsed by the Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]), the Assistant Secretary of Defense for Networks and Information Integration (ASD[NII]), and the Director of Operational Test and Evaluation (DOT&E), Office of the Secretary of Defense. DODI5000.02 provides guidance and governance for DoD acquisitions, and identifies a need for a capability-based technology needs definition:

> "[This instruction] Establishes a simplified and flexible management framework for translating capability needs and technology opportunities, based on approved capability needs, into stable, affordable, and well-managed acquisition programs that include weapon systems, services, and automated information systems (AISs)."

Furthermore, DoDI5000.02 requires all capability needs and acquisition management systems shall use "integrated architectures" to conduct DOTMLPF analyses. By addressing DOTMLPF solutions, DoDI5000.02 lays the groundwork for integrating activities across the Navy, from Fleet organizations to Systems Commands (SYSCOMs). The instruction goes on further to empower milestone decision authorities to determine whether sufficient information has been provided to advance program-of-record development. Through the pursuit of mission architecture using a Fleet-first approach, CBMM-compliant architectures can better inform milestone decision authorities and aid in determining which material or non-material solutions are best suited to address needs identified in initial capabilities documents. These architectures also inform internal and external oversight organizations of the state of enterprise readiness for new DoD acquisitions that supports compliance with net-ready key performance parameters.

With the signing of DoDI5000.02, architectures require entrance criteria into the production and development phase of the Defense Acquisition System. Because CBMM begins with a Fleet-first approach to map into system functionality and overall mission performance, it provides a comprehensive methodology for satisfying these requirements and ensuring that architectures can appropriately manage data needed to guide requirements definition, M&S specification, and anticipate future I&I issues with the existing or future Fleet.

1.4   Signing of I&I Charter

In December 2012, an I&I charter was signed by the Vice Chief of Naval Operations to establish an office in the Office of the Chief of Naval Operations that would be responsible for developing methods and approaches to assess "I&I gaps from a mission area kill/effects chain perspective." With this charter, I&I funded organizations were commissioned to assess current Fleet capabilities and determine the effects of emergent technologies on the existing enterprise. The charter also establishes governance and a battle rhythm for future I&I tasking.

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The I&I charter, similar to DoDI5000.02, while extremely effective in establishing mission engineering as a core Navy competency, does not specify a methodology or approach to be taken for architectural development. This is largely owing to the inexperience of many organizations to model Fleet operations using architectures. By exploring multiple approaches to architectural development in Navy I&I and alongside Fleet organizations, CBMM has evolved from a concept to a repeatable practice that satisfies the mission architecture needs articulated in the I&I charter. CBMM, by modeling the complete context of Fleet desired effects, produces an architectural approach that supports the I&I goal of relating data relevant to current Fleet readiness and the impact of current or future DOTMLPF solutions on the existing enterprise.

2.0   FLEET-FIRST, CAPABILITY-DRIVEN MISSION MODELING

Given the complexity of managing mission data, conceptual aids are useful to describe CBMM as an architectural approach and to address how it accommodates the interests of multiple Navy enterprise stakeholders. A data model is also essential to identify diverse data type relationships and which core models are most useful for data management functions.

2.1   Acquisition Triad

DoD acquisitions can be conceptualized through a three-sided figure representing the Fleet and Department of the Navy (DON) leadership, the operational community, and the technical community as modeled in Figure 2.
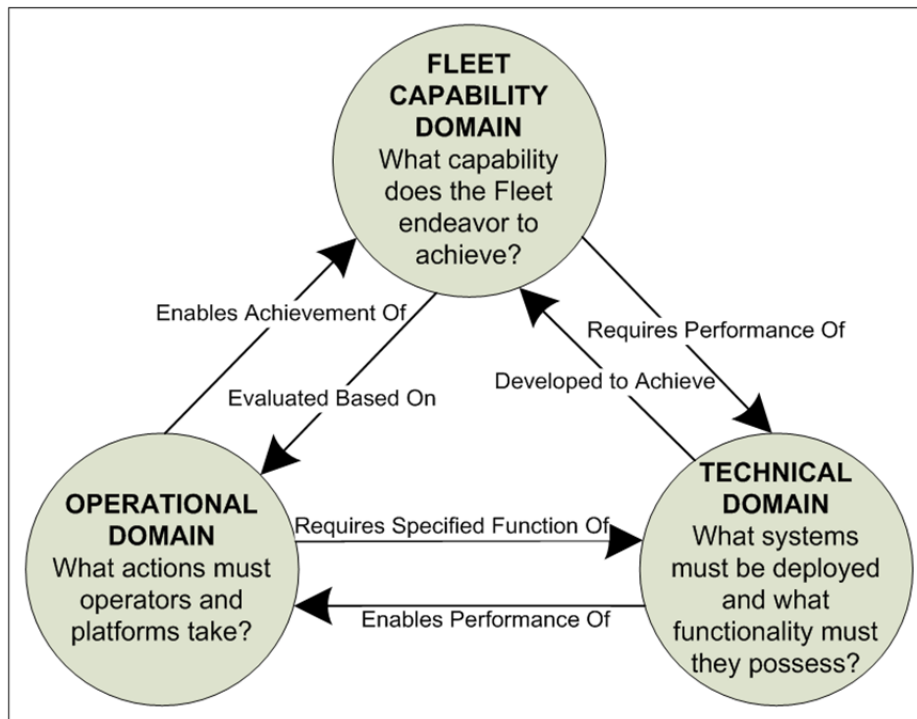
Figure 2: Acquisition Triad

This triad demonstrates the interdependence that exists among all stakeholders in Navy acquisitions and in the several Navy communities of interest. This same construct can be used to describe non-Navy organizations but will be limited in this report to the DON.

Each node represents group or organizational interests, which for many organizations may mean many stakeholders across multiple domains. The triad becomes most useful in, first,

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identifying the nature of an organization's interests and, second, in associating the interdependence that exists among these interests. Once an understanding is reached that seemingly unrelated interests are related, it becomes easier to begin the process of identifying essential data elements required to comprehensively model the enterprise.

Needlines between nodes represent this interdependence. The CBMM purpose is not to establish these relationships but rather to identify and augment the current state of cooperation among interests. For example, Joint Urgent Operational Needs (JUON) statements are used to articulate requirements of the Fleet Capability Domain to the Technical Domain for the purpose of a material solution. These statements provide great deals of information to the technical community but may not be sufficient for producing the "right thing" for the "right problem." CBMM architectures allow for identification, collection, and analysis of the problem expressed in these JUONs so clearer requirements can be delivered to the engineers and a better, more efficiently integrated solution can be delivered to warfighters.

2.1.1 Fleet Capability Domain Perspective

Fleet capabilities and known gaps are managed and prioritized in higher Navy echelons. Part of this prioritization occurs as a result of the known development of current systems (represented by the "Developed to achieve" needline originating from the technical domain) and from the current status of existing Fleet readiness (represented by the "Enables achievement of" needline originating from the operational domain). Fleet capabilities drive material development through requirements definition (represented by the "Requires performance of" needline) and guide the evolution of doctrine and training through iteratively evaluating existing procedures (represented by the "Evaluated based on" needline).

2.1.2 Operational Domain Perspective

The operational domain includes those stakeholders responsible for executing defined capabilities using established training, existing platforms and systems, and current doctrine. Their actions are limited by material readiness ("Enables performance of" needline) and guided by doctrine and priorities established by senior DON leadership ("Evaluated based on"). The operational domain relies on the technical domain to develop and deploy systems capable of supporting operations in defined environments and conditions ("Requires specified function of" needline). The operational domain also interacts with Fleet leadership through evaluation of its ability to achieve specific capabilities ("Enables achievement of" needline), which provides feedback to naval leadership regarding Fleet readiness. Through assessment of current Fleet readiness, leadership then refines capability needs to senior strategic planners who redirect technical priorities ("Requires performance of" needline).

2.1.3 Technical Domain Perspective

The technical domain is primarily concerned with developing, improving, or maintaining material solutions to capability gaps established by the Fleet capability domain. Traditionally, limited iterative interaction exists between the Fleet and the SYSCOMs ("Requires performance of" needline), which can result in system requirements that lack the technical rigor or operational context to provide what warfighters truly need or are capable of employing. SYSCOMs work to develop systems to their design requirements established by Navy leadership ("Developed to achieve" needline). Unfortunately, due to the complex and ever-changing nature of war, requirements that are either not developed using a rigorous engineering approach or fail to

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address the evolving state of naval warfare risk produce material solutions that do not efficiently integrate with the Fleet or do not suitably meet the operational domain's need.

The risk of insufficient or incomplete requirements definition is directly related to the ability of the Navy enterprise to share and understand information. The data exchange, performed without the aid of a tool such as mission architecture, can become overwhelming and difficult to maintain.

CBMM provides a vehicle for capability, operational, and technical collaboration. It also provides a vehicle for the technical community to validate its material solutions with the Fleet prior to and during system testing ("Requires specified function of" needline) and increases the likelihood the delivered system integrates with the Fleet ("Enables performance of" needline) without requiring extraneous training or inefficient post-development integration measures.

2.2 Symbiotic Relationships Between Domains

The acquisition triad is built to not only communicate types of interest each stakeholder takes in the mission but also the relationships between those stakeholders (see Figure 3).
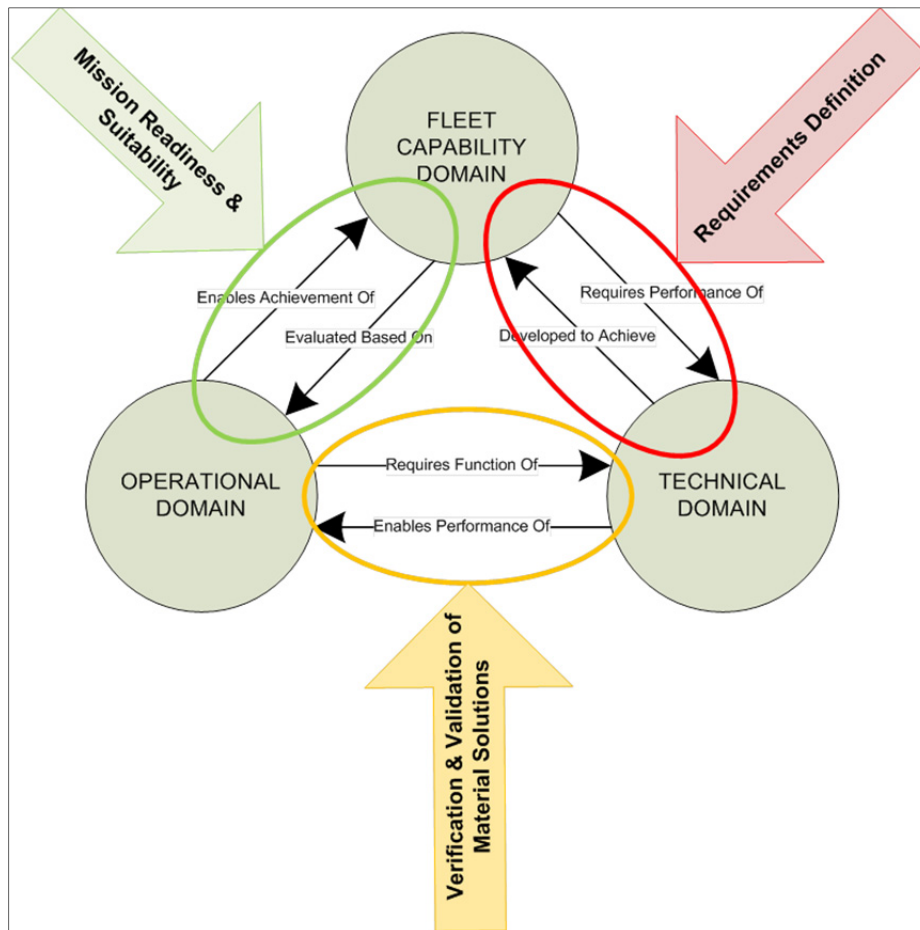
Figure 3: Application of Acquisition Triad to Current Navy Activities

As discussed, the relationship between the Fleet capability domain and the technical domain exists in requirements definition and satisfaction by way of material solutions. The relationship between the technical and operational domains can be found in the verification and validation of

material solutions and the deployment of new systems entering initial operational capability or relevant operational testing. The relationship between operational and Fleet capability domains exists throughout United States Fleet Forces' calendar of Fleet experimentation and training events as well as in-service Fleet readiness reports. Collectively, this forms a symbiotic relationship among members of all three domains and speaks to the need for a modeling approach that can manage the resources and needs of all stakeholders.

The triad makes no efforts to represent the strength of each relationship, either in theory or practice. The Fleet capability and operational domains often consist of similar organizations that share common interests that strengthen their relationship. The technical domain does not share the same organizational ties to warfighters that operational and capability domains share. For example, SYSCOMs operate under a management structure not dissimilar to Fleet organizations but are not tied to any particular Fleet or operational organization. This introduces a communication barrier among those in the technical domain who may not clearly understand operations but are still responsible for developing systems for key operational stakeholders. This lack of interaction with the Fleet, paired with a mentality that the "customer" is the organization that provided an initial list of system requirements, results in fielded systems that do not fully support warfighters in the manner theater commanders want to fight or satisfies all system requirements with the exception of employment; often unpredictable at the time of initial requirements definition.

2.3 Data Model

A data model was created for tasks established in the I&I charter to map complex data relationships managed in mission architecture. This model, referred to as the Integrated Capability Framework (ICF) Data Model, is illustrated in Figure 4.
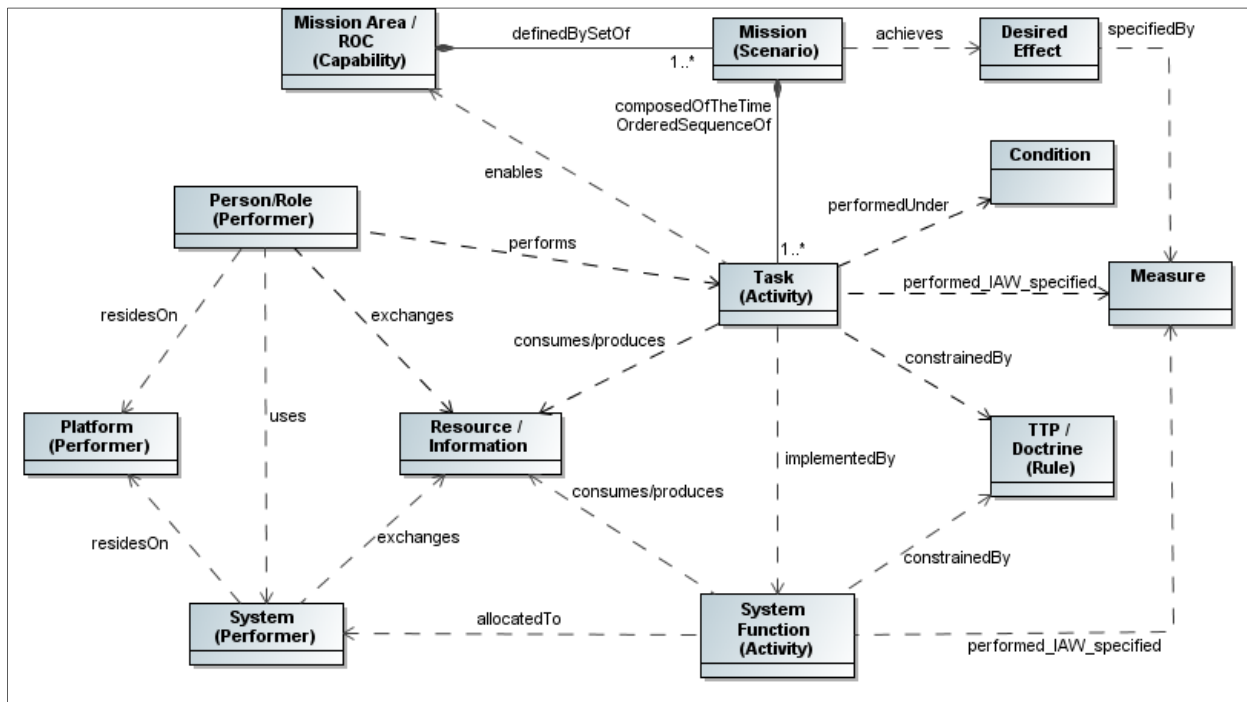
Figure 4: ICF Data Model

The ICF Data Model is based on DoDAF Meta Model compliance and the needs of the ICF to better inform acquisition practices and requirements definition. In the CBMM instantiation of the ICF Data Model, two additional connections can be drawn: "System Functions" to "Mission Area and Capabilities" and "Mission Focus, Scope, and Purpose" to "Rules and Doctrine." This allows for scoping missions based on current and future doctrine and creates a critical data relationship between capabilities and system functions that identifies which material requirements exist to achieve a given capability. Some terminology from the ICF data model has been changed for ease of use and understanding by architects not familiar with the ICF, as shown in Figure 5.
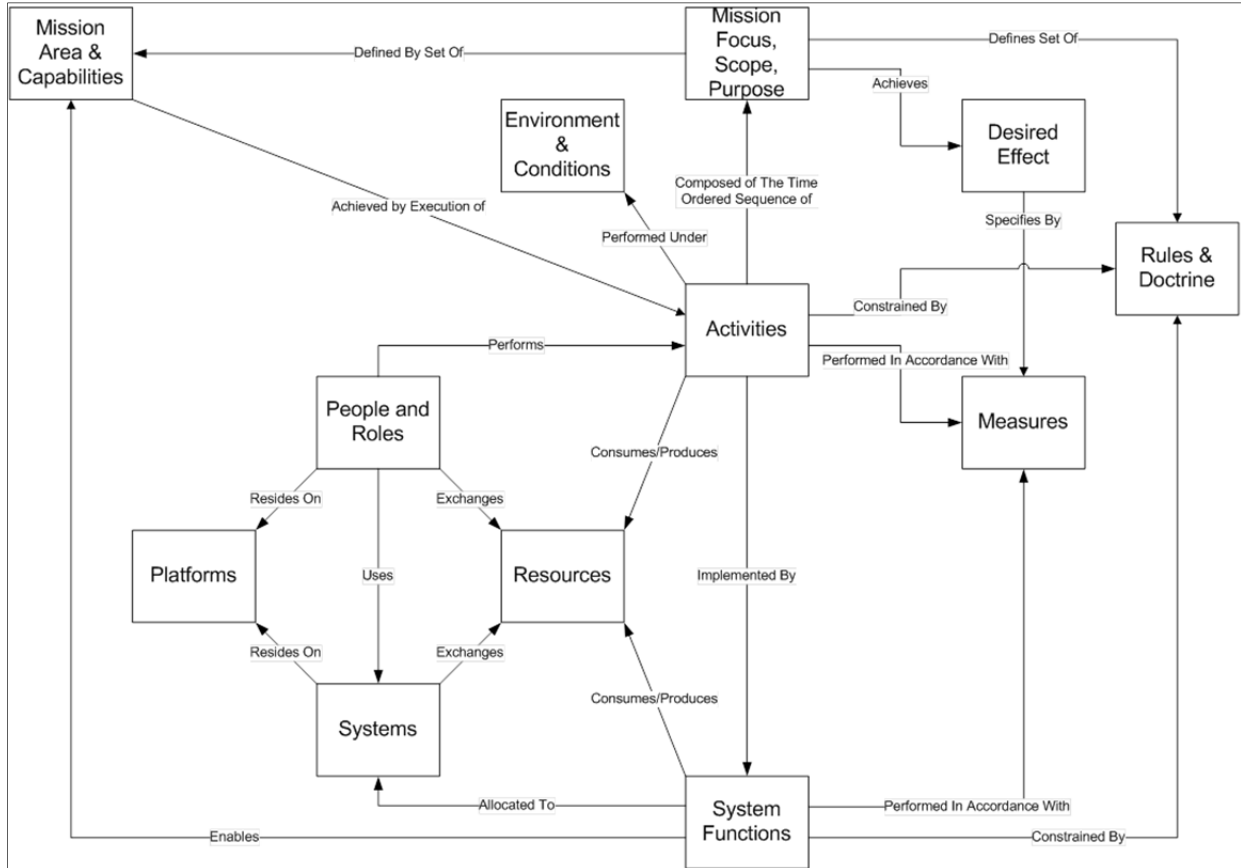
Figure 5: CBMM Data Model

The CBMM data model creates a mechanism that allows for organizing data that comes from and is consumed by multiple stakeholders across all domains of the acquisition triad. Using this data model, architects can determine suitable methods for parsing and managing available data and data needs present throughout the enterprise. Models deemed essential, or "core," to CBMM will represent critical relationships identified in the data model.

By superimposing the CBMM data model onto the acquisition triad in Figure 6, architects can relate specific data elements and relationships to individual stakeholders.
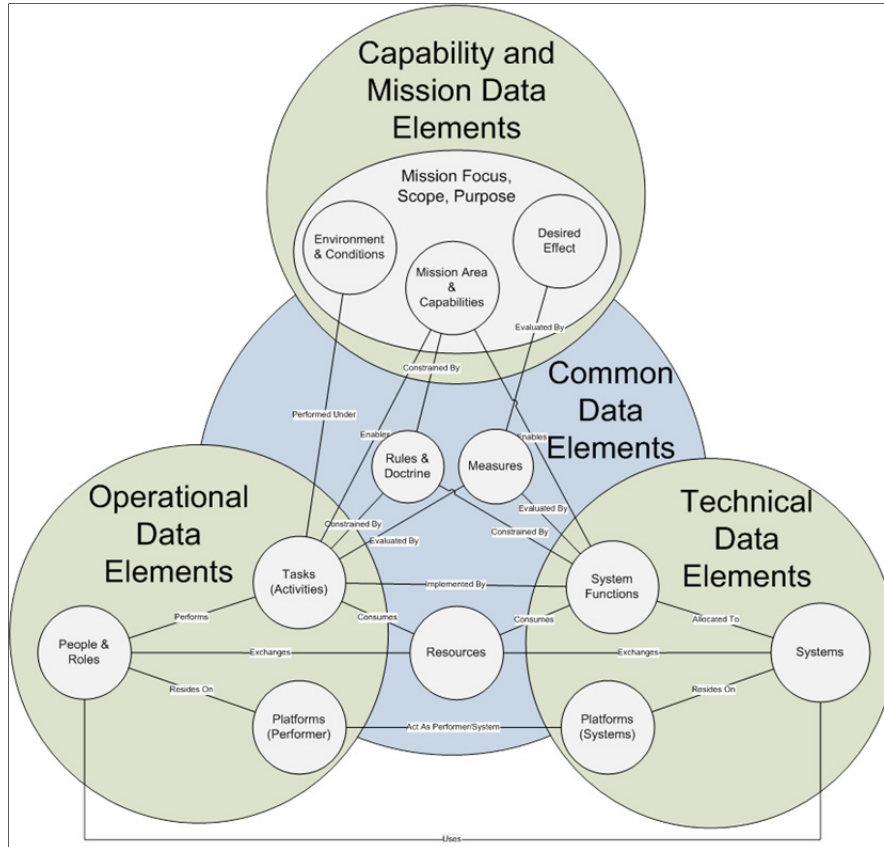
Figure 6: CBMM Data Model Superimposed on Acquisition Triad

3.0   ARCHITECTURAL APPROACH

CBMM also specifies an architectural approach for manipulation and management of the data model. This approach uses readily available authoritative data sources from the DON, which standardizes architectural products across multiple efforts and accommodates product reuse without the need for costly reconciliation of inconsistent taxonomies.

The following development sequence is a suggested roadmap to generating a CBMM mission architecture. Architectures are built in an iterative manner meaning that some steps may be conducted multiple times. Data availability and data needs may also necessitate some steps being accomplished out of order. Regardless, the sequence provided has been useful in capturing Fleet operations and in efficiently managing data across a multimission area enterprise.

3.1   Summary and Overview and Scenario Documentation (AV-1, OV-1)

An Architectural Summary and Overview (AV-1) defines the purpose, goals, scope, and questions to be answered by the final architecture product. When built in accordance to DODAF 2.0, the AV-1 serves as a commonly understood product that aids in coordination among all domain stakeholders for architectural scoping and development. CBMM encourages including references of all data in the AV-1 to attributed sources, sponsors, stakeholders, or authoritative sources. This discourages arbitrary architectural development and creates a level of accountability in architecture by establishing under whose authority or expertise assumptions, scope, or other identifying information was established. To aid in planning and execution, stakeholders may be aligned in the acquisition triad to help identify the nature of data needs.

It is common practice for programs of record, Fleet organizations, or system authorities to develop Design Reference Missions (DRMs) to guide testing and design evaluation. CBMM encourages decomposing these DRMs into architectural elements, applying the DRM scope to the AV-1 and the DRM description to the High-level Operational Graphic (OV-1). As required by DoDAF 2.0, the OV-1 should include a narrative outlining the mission's conditions, assumptions, and scope in sufficient detail to guide operational viewpoint (OV) development. DRMs may contain a sufficient level of detail to serve as the accompanying OV-1 narrative, which would enable an architect to directly import already established DRM metadata into a CBMM-compliant DoDAF architecture, more easily integrating mission architectures in the conventional acquisition system or existing organizational processes.

The AV-1 contains summary data from every CBMM data model data element. The OV-1 contains data (highlighted in yellow in Figure 7) regarding the mission to be performed, capabilities to be achieved, conditions under which operations will occur, and the overall desired effect.

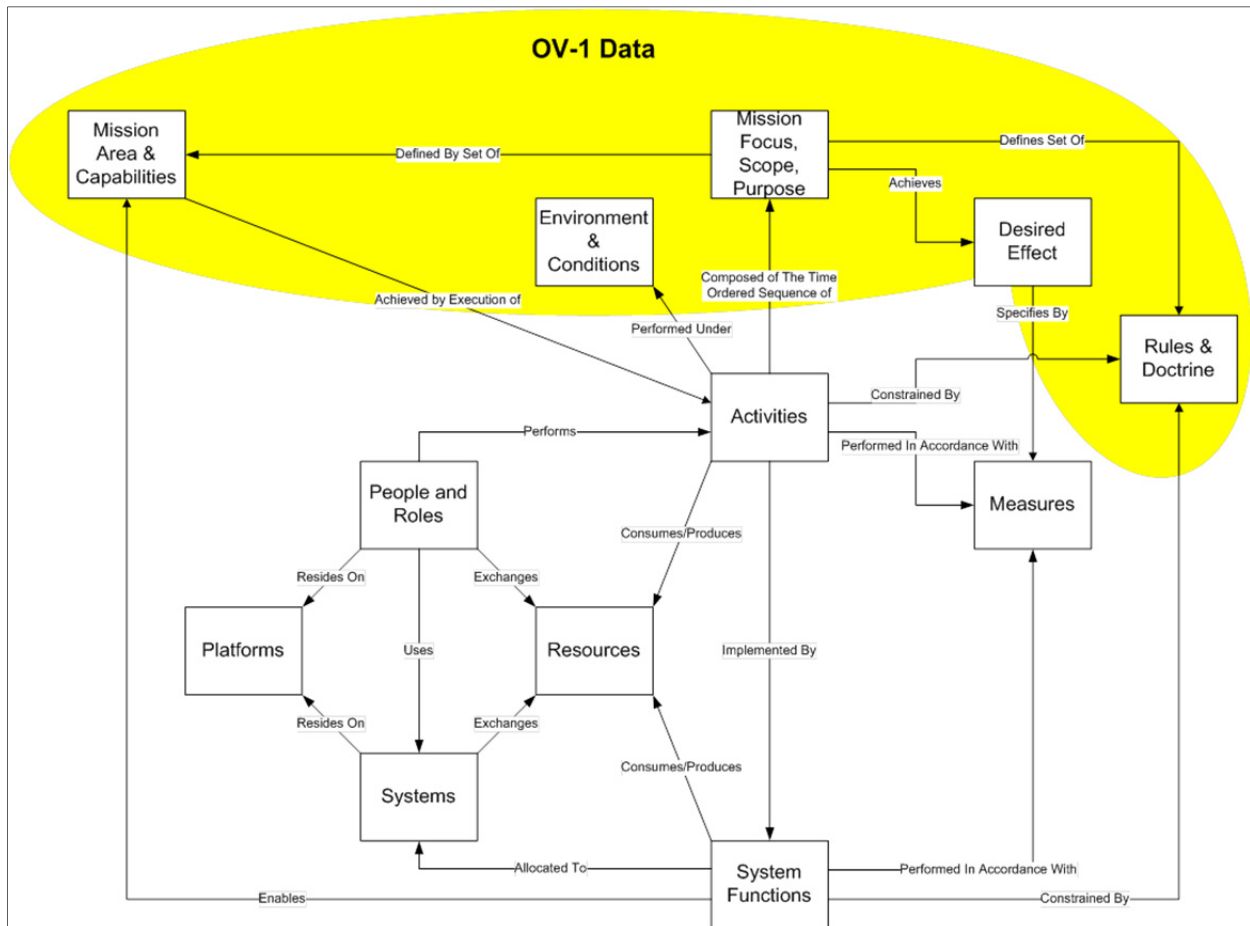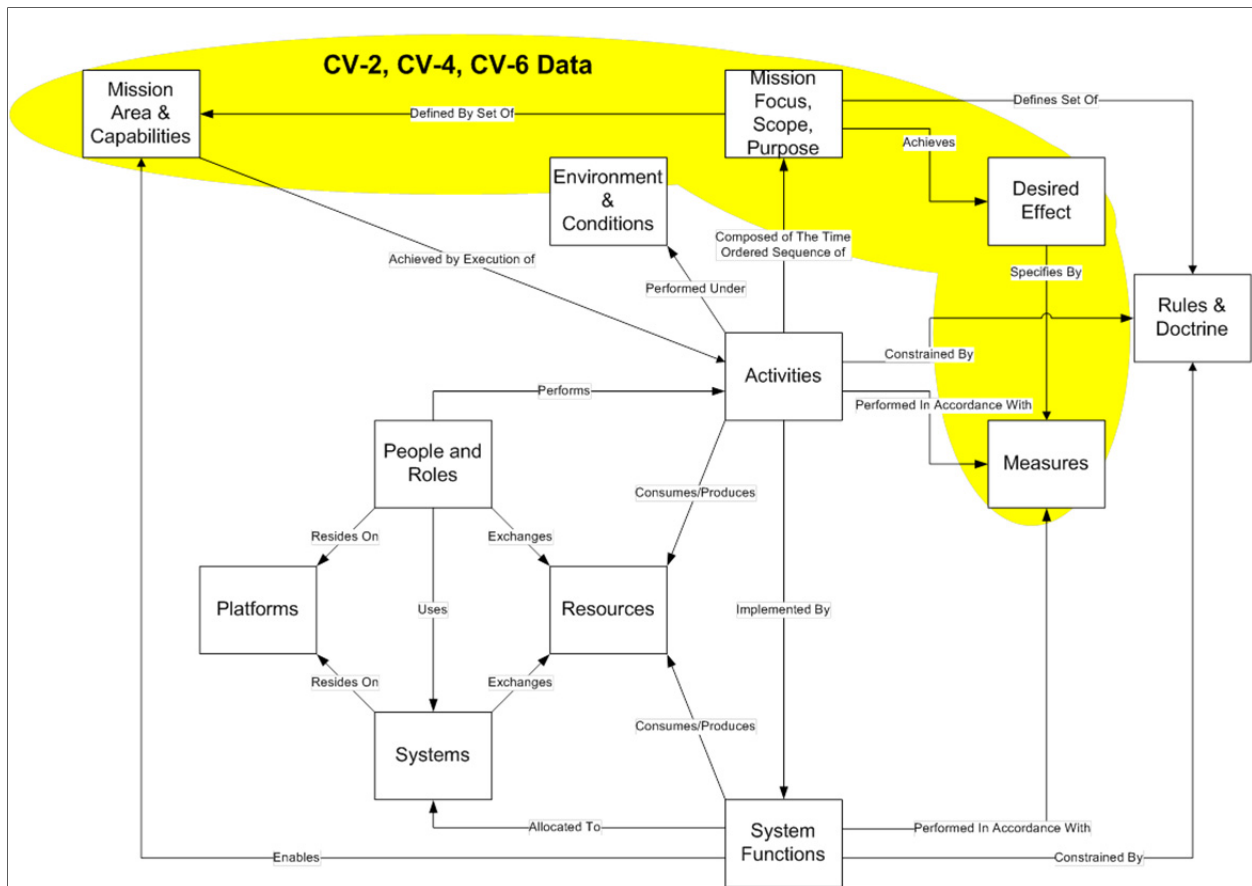**Figure 7: Primary OV-1 Data Elements in the CBMM Data Model**

3.2   Capability Definition and Activity Mapping (CV-2, -4, -6)

The Fleet's desired effect drives which capabilities and dependent capabilities are included in the architecture. If these desired effects are included in a DRM or reference tactical situation (TACSIT), then establishment of capabilities modeled in an architecture's capability viewpoints

(CVs) becomes a matter of simply mapping desired effects to the capabilities listed in authoritative taxonomies, such as the Required Operational Capability/Projected Operational Environment or Joint Capability Areas. Once capabilities are derived and mapped to authoritative sources (e.g., DRMs, TACSITs), they can be modeled in a hierarchy by using a Capability Taxonomy (CV-2). If no authoritative source exists from which capabilities can be derived, it is incumbent upon the architect to seek validation of capabilities from an authoritative source or Fleet command. Such sources should be noted in AV-1 and validated with the intended architecture consumers. Capability dependencies can often be established using the same set of authoritative sources and documented in the Capability Dependencies Description (CV-4). Data required for generating CV-2, -4, and -6 models are highlighted in yellow in Figure 8.

Figure 8: Primary CV-2, CV-4, and CV-6 Data Elements in the CBMM Data Model

Before continuing to operational activity modeling, it becomes necessary to establish activities required to satisfy each capability noted in the CV-2. These activities can be modeled in a Capabilities-to-Activities Description (CV-6). This model can traditionally be achieved through a matrix or spreadsheet. CBMM increases the level of detail in the conventional CV-6 by including interactivity dependency mappings required to achieve each capability. The resulting model visually resembles an Activity Model (OV-5b) but is scoped to a single capability making it satisfy CV-6 data requirements.

Figure 9 is an example of a CV-6 created to model activity relationships in a single capability and resembles a simplified version of an OV-5b. The viewpoint shows several Navy tactical tasks (NTAs) connected to externally identified NTAs that exist in separate capability areas. In

Figure 6, capabilities are taken from the Navy's Required Operational Capability established in Office of the Chief of Naval Operations Instruction C3501.2K, (U) "Naval Warfare mission Areas and Required Operational Capability/Projected Operational Environment (ROC/POE) Statements." NTAs identified as critical by the Fleet via the Navy mission-essential task list have been highlighted in gold. By producing a CV-6 as an activity mapping scoped to a single capability or sub-capability, operations are "modularized" by capability, allowing them to behave as building blocks for a larger mission architecture. This modularity has both programmatic and architectural development advantages over more traditional approaches.
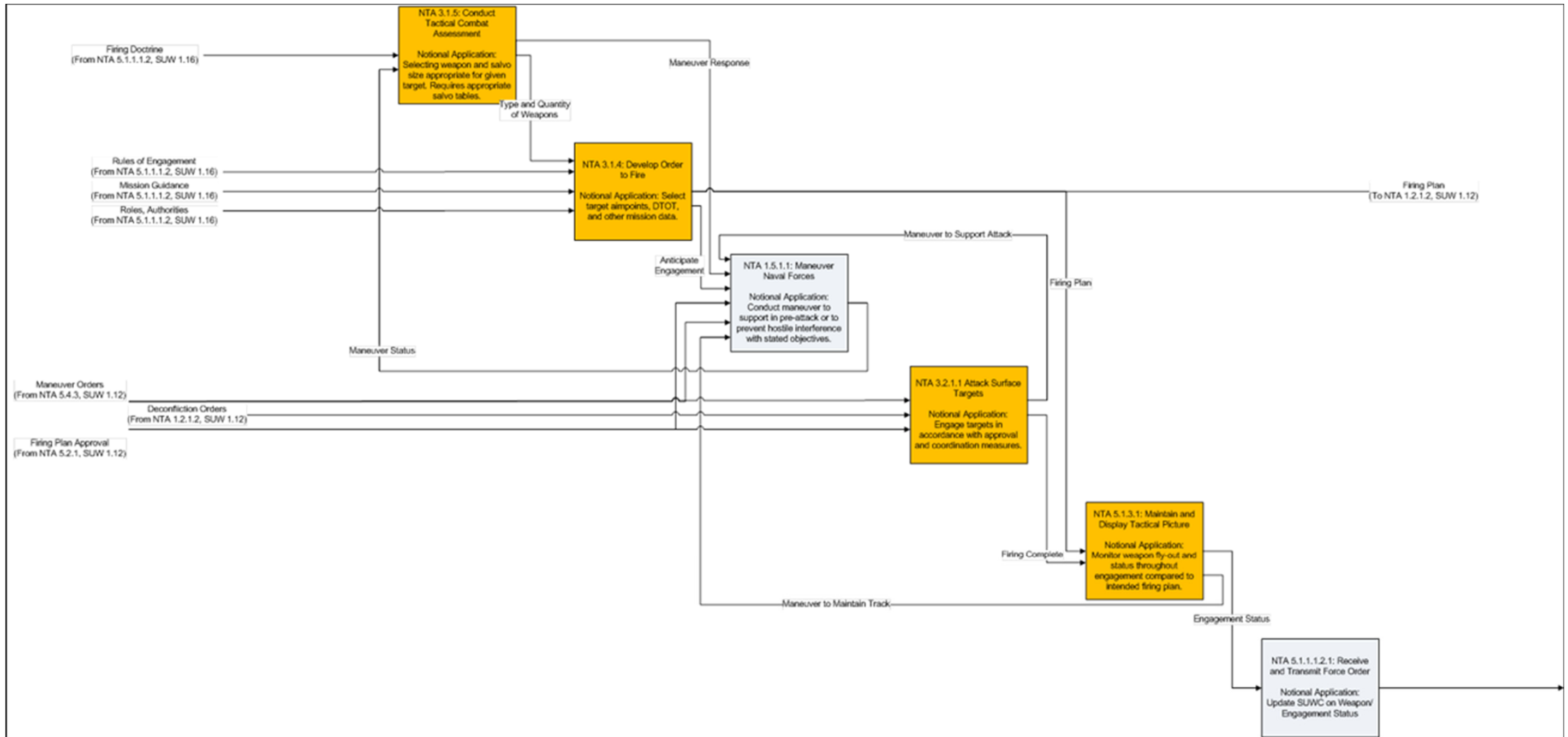
Figure 9: Activity Model Scoped to Single Capability Forming a Single CBMM CV-6 Module

3.2.1   Modularity's Impact on Future Effort, Manning, and Investment

Modularity becomes increasingly important to the architect as each viewpoint goes through validation and accreditation with stakeholders and data owners. Conventionally, architecture accreditation or validation becomes a difficult process that involves mapping all data elements to either authoritative sources or documentation. This mapping represents a large financial effort for sponsoring organizations. If the modular approach in CBMM is followed, individual CV-6 viewpoints may be accredited individually. This creates circumstances where architectures can be validated and accredited once and reused for future efforts without additional investment.

As experienced throughout the Navy I&I effort, architecture reuse, through modularized CV-6 viewpoints, has a "stacking effect" on program investment savings over time, as illustrated in Figure 10.
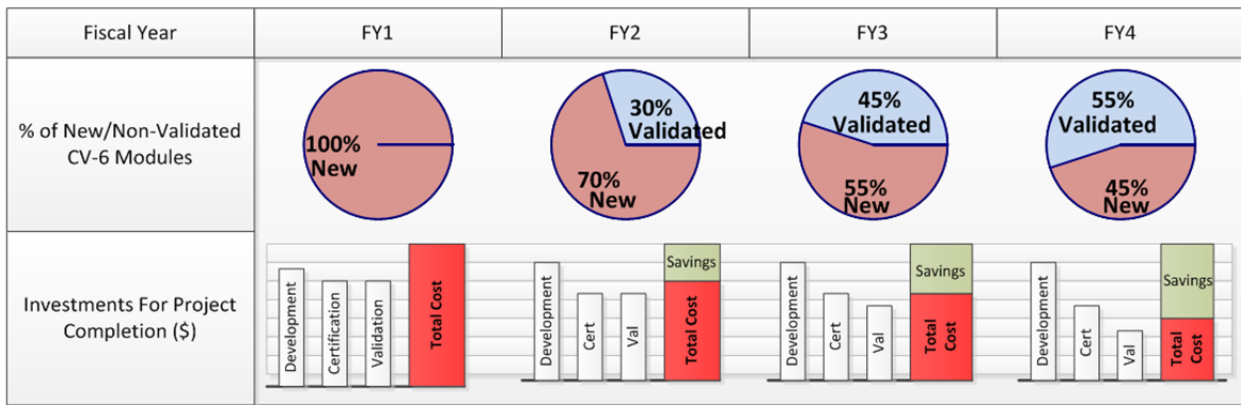
Figure 10: Notional Cost Saving of Modular CV-6 Design with Validation/Certification Carryover

The tradeoff introduced by this type of modular reuse is in the validation of previous architecture conditions and assumptions. If a preceding architecture was developed under a dramatically different set of operating conditions or environment, some revalidation may be required. However, even under these circumstances, the preceding architecture is still useful as a starting point for architecture development that results in increased developmental efficiencies.

3.2.2   Utility of CBMM CV-6 Build-up to OV Generation

A mission is completed by achieving a series of interconnected capabilities. These dependencies can be identified and analyzed in the CV-4. Since all activities required to achieve each capability are identified through modularized CV-6 viewpoints, the task of creating activity models (OV-5a and OV-5b) becomes simpler. Identifying activity relationships becomes a simple matter of merging activities required to achieve each separate capability with the dependencies between each capability. Figure 11 illustrates this process.
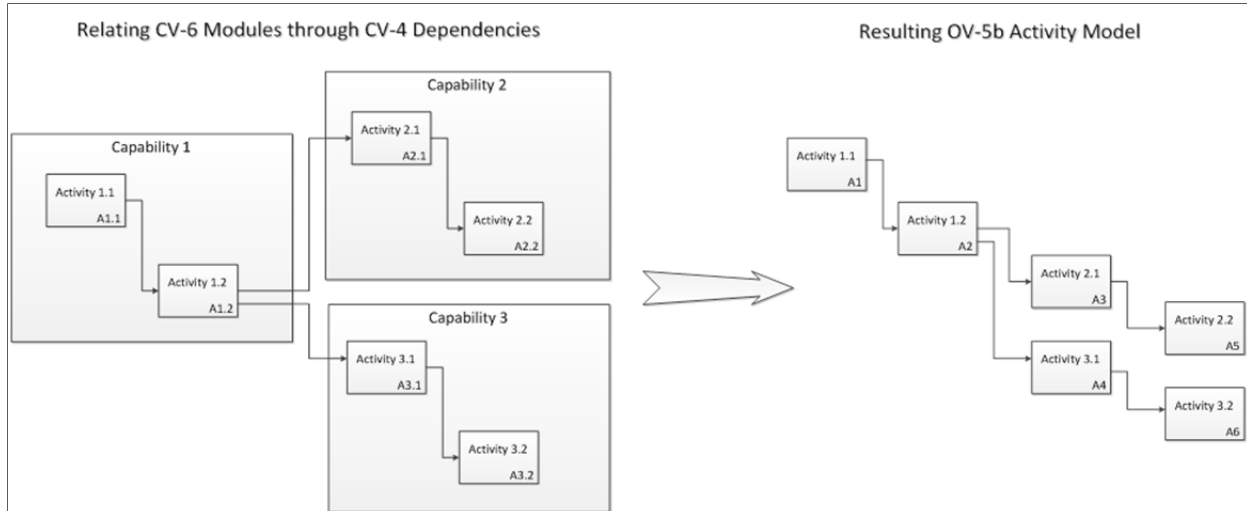
**Figure 11: Combining Modularized CV-6 Models Through CV-4 Capability Dependencies
to Produce Activity Models**

3.3 Activity Models (OV-5a, -5b)

Traditionally, the OV-5a and OV-5b would be the first or one of the earliest instances in an architecture where activities are defined and their dependencies established. CBMM differs from convention in pulling both activity definition and interactivity mapping from data modeled in CV-6 models. This developmental relationship between CV-6 and OV-5 diagrams forms one of the CBMM product cornerstones.

A key CBMM tenet is that an activity, without context of a capability, is ambiguously defined, rendering it ineffective for modeling real-world operations or for reuse in modeling and simulation (M&S) or other types of analysis. Depending on the desired effect, an activity may be implemented and defined a number of ways. This reality requires that activities be defined first in CV-6 models before being mapped together in an activity model. The data required to generate the OV-5 is highlighted in yellow in Figure 12.
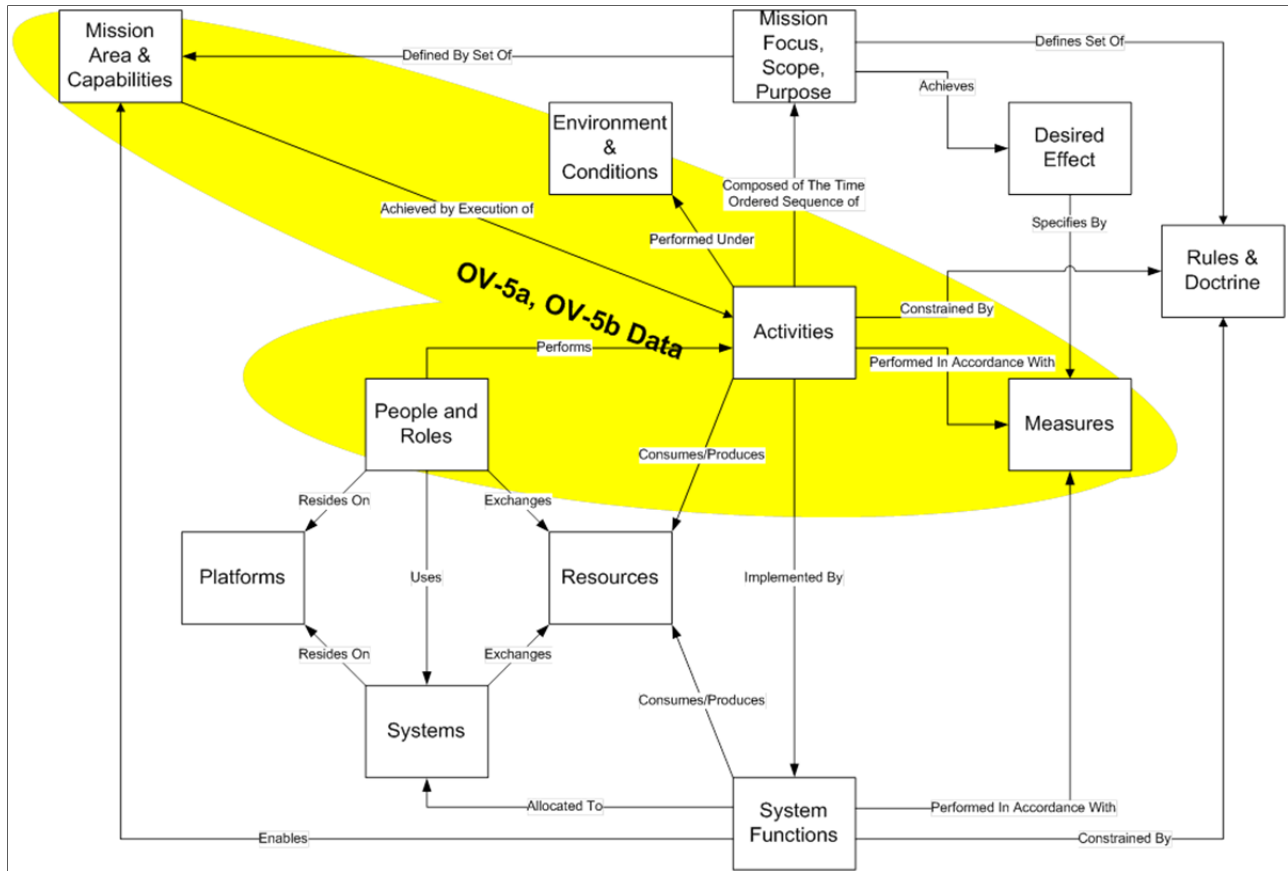
Figure 12: Primary OV-5 Data Elements in the CBMM Data Model

In practice, managing these types of dual activities becomes difficult. Current architectural tools are built to support DoDAF but not necessarily built for mission architecture development; vice enterprise, organization, or system architectures. This may require a unique numbering system or an independently maintained index of activities as they occur in different capabilities. Because of the diversity in architectural tools currently used by different stakeholders, it is the responsibility of the architect to ensure activity taxonomies are properly managed to avoid ambiguity in activity definitions and interpretations.

3.4   Determining Technical Relationships to Activities (SV-1, -4, -5a, -5b)

Traditional architectural methodologies begin generation of system viewpoints (SVs) by defining the systems of primary interest in an Interface Description (SV-1) model. This approach is useful only when the available systems are highly controlled. Unfortunately, Navy missions may use multiple baselines of common systems as well as many systems irrelevant to the current architectural effort. The architect's systems of primary interest are dictated by the activities and performers necessary to achieve the desired effect.

Therefore, the CBMM approach of defining systems is through an assessment of what is required to execute activities as defined in the OV-5. The resulting model is a mapping of systems and their system functions, to activities in an Operational Activity-to-Systems Function Traceability Matrix (SV-5a) and an Operational Activity-to-Systems Traceability Matrix (SV-5b). Concurrent with the construction of SV-5a and SV-5b models is the mapping of systems to the system functions (SV-4) that must be performed for mission completeness.

Once the systems necessary to execute each identified activity have been established, but not *prior* to establishing those systems, each system may be related through an SV-1. Data required to generate these SV products are highlighted in yellow in Figure 13.
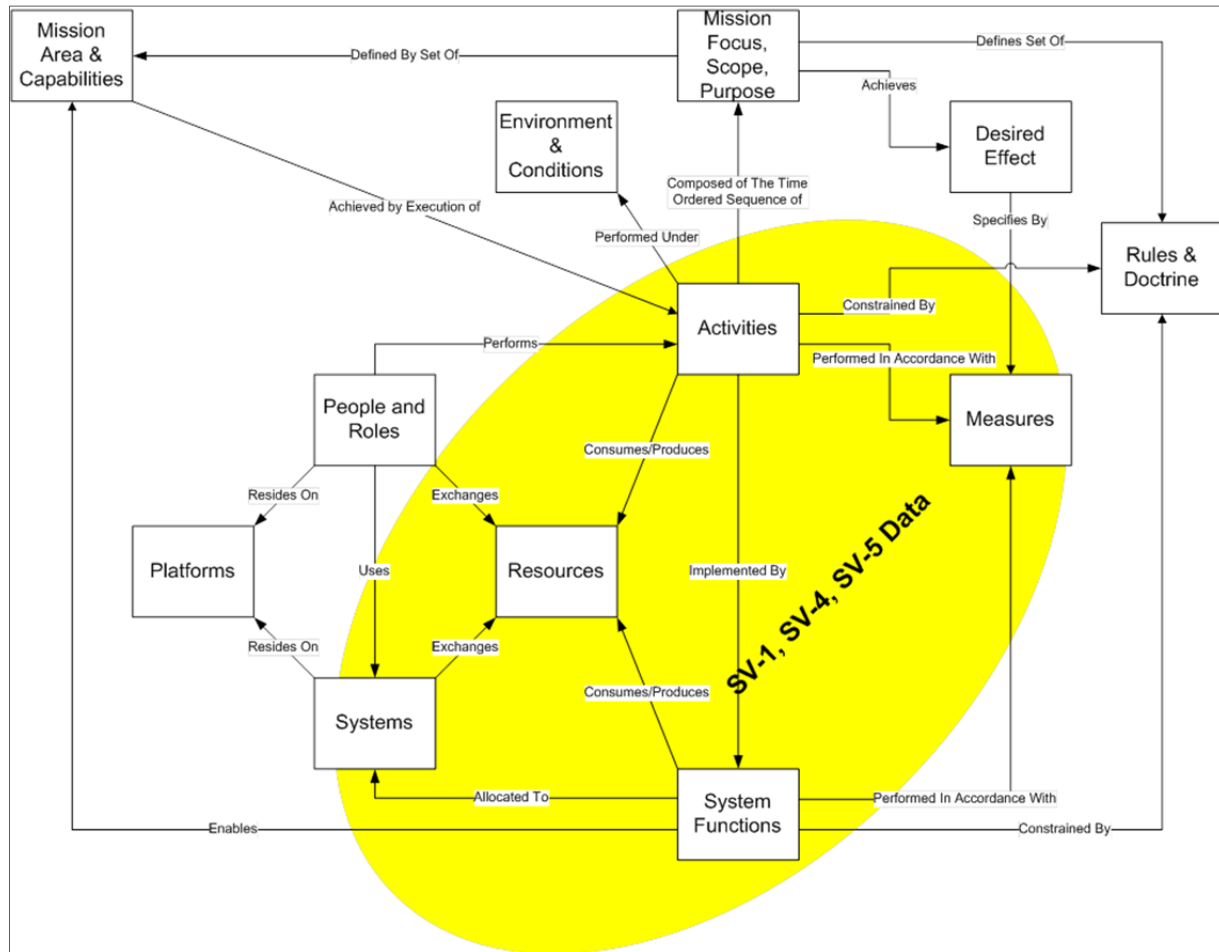
Figure 13: Primary SV-1, -4, and -5 Data Elements in the CBMM Data Model

SV-1 generation during early developmental phases may still be beneficial for early planning, collaboration, and coordination between organizations. If the SV-1 is created prior to establishing a firm understanding of the activities to be performed and the performers available for the mission, the architect must articulate to leadership the high likelihood of dramatic changes in the interface description.

3.5   Modeling Operational Context (OV-2, -3, -4)

CBMM does not have any unique modifications or recommendations for construction or management of either the resource exchange description (OV-2) or a resource exchange matrix (OV-3) other than guidelines already provided in DoDAF 2.0. Since the command and control structure for a mission and the available resources and performers are often established by doctrine or current Fleet realities, these products are not necessarily reliant on establishing capability or activity taxonomies for generation. For this reason, CBMM recommends these viewpoints be drafted and updated in parallel to other model development efforts. The relationship between critical OV-2, -3, and -4 data elements and the CBMM data model is highlighted in yellow in Figure 14.
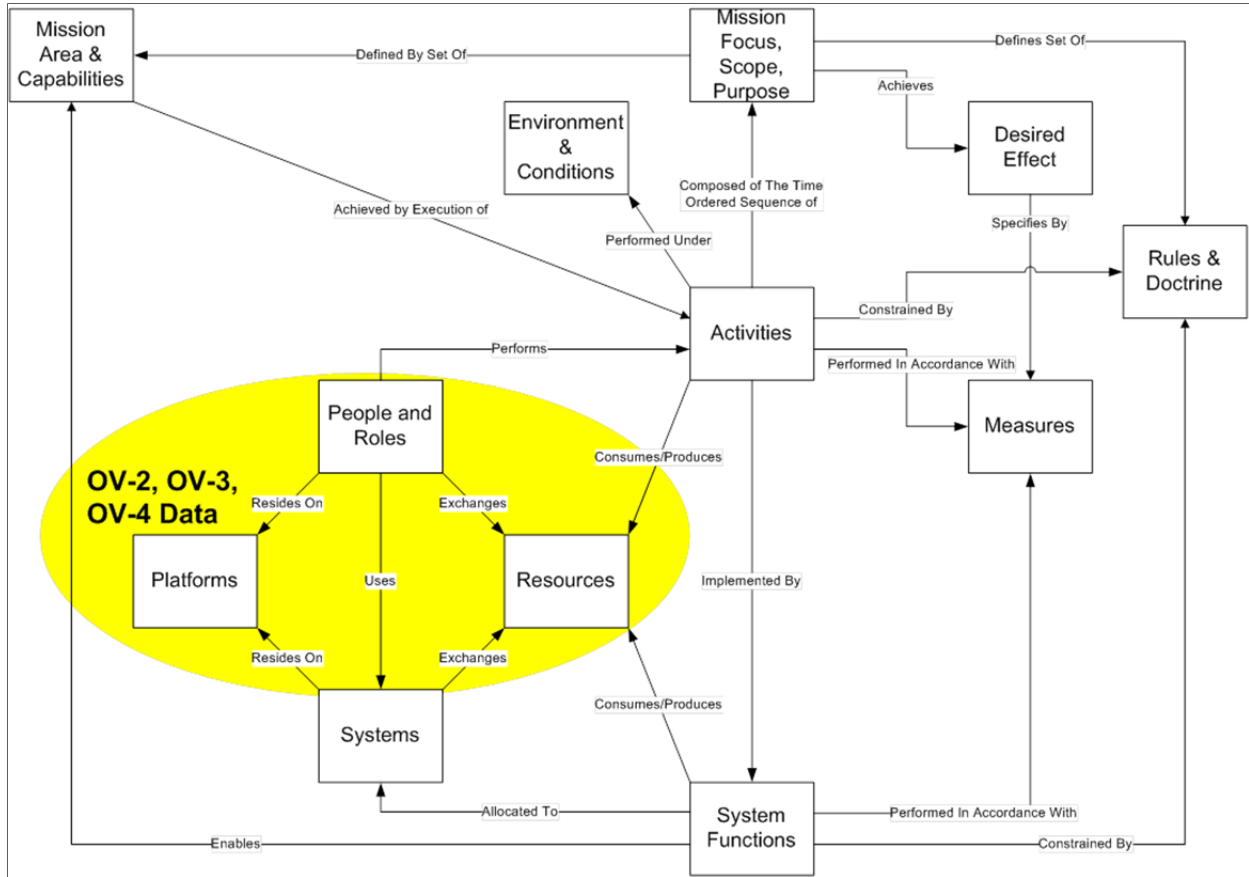
Figure 14: Primary OV-2, OV-3, and OV-4 Data Elements in the CBMM Data Model

3.6   Mapping Systems and System Functions to Capabilities (CV-5)

The Organizational-to-Capability Description (CV-5) can be tailored to model which performers or organizations are responsible for a given capability and which systems they use to achieve a desired effect. Traditionally, this viewpoint would be used to map organizations responsible for executing and achieving a desired effect. In CBMM, tailoring of this model encourages mapping technical stakeholders to modeled capabilities. This allows the architect to establish the dependencies of primary Fleet stakeholders on the technical community. In the context of Fleet exercise and experimentation planning, this model aids in determining the level of impact and criticality of technical organizations to the larger mission. Data required to generate these products are highlighted in yellow in Figure 15.
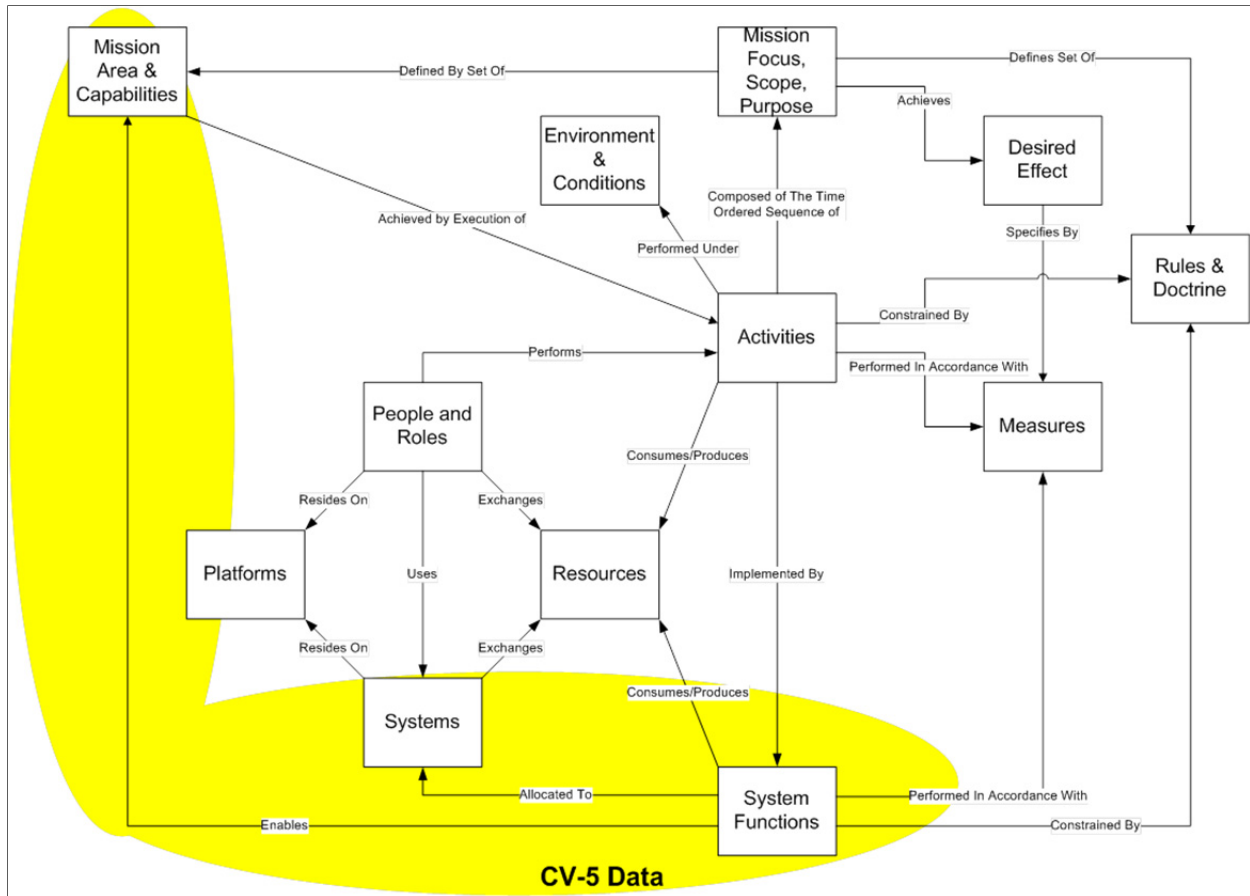
Figure 15: Primary CV-5 Data Elements in the CBMM Data Model

3.7 Optional Technical Requirements and Needs Models (SV-2, -3)

CBMM maintains no unique recommendations or guidance toward the creation of the System Resource Flow Description (SV-2), Matrix (SV-3), and Systems Functional Description (SV-4) but does recognize them as critical viewpoints to understanding the nature of systems throughout the mission. These resource-level viewpoints allow program offices and systems engineers to determine how a particular system interacts with peer systems.

3.8 Optional Operational Mission Threads and Effects Chains (OV-6 and SV-10 Models)

CBMM recognizes the utility of mission threads (OV-6a, OV-6c) and effects chains (SV-10a, SV-10c) for specific purposes. As with any model, CBMM architectures must be validated. For computational models, the modeler can validate assumptions and algorithms through execution of the model under known conditions with a known outcome. Similarly, an architecture can be "executed" by forming a time-sequenced thread of activities or chain of system functions that describe how activities and system functions are executed in real time under relevant conditions. These mission threads and effects chains can be applied to Fleet exercises, simulations, or operational testing where the conditions of the events are clearly understood. By verifying events are executed as the mission thread or effects chain indicated, an architect can validate the data and data relationships contained in the mission architecture. The number of mission threads or effects chains necessary to validate logical data relationships in an architecture depends on the comprehensiveness of each thread or chain, what architectural elements have already been

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validated through previous architectural efforts (using the modular design of the CV-6), and the desires of stakeholders defined in the AV-1.

In CBMM, mission threads and effects chains are used primarily for validation and collaboration. Validation of architectural models, communication with stakeholders in the technical and operational domains, and quantifying critical mission measures are all useful applications of threads and chains. If the questions to be answered and objectives in the AV-1 have been appropriately scoped, these threads and chains can also be effective in conceptualizing development of M&S tools to feed further analysis. What is not encouraged by CBMM is the use of a mission thread to drive or scope architectural development. A mission thread may contain all activities and system exchanges that occurred during a single instantiation of time, but that does not assure the thread is inclusive of all possible activity and system relationships that may exist throughout the enterprise. Therefore, the architecture must be driven by the desired effects articulated by the Fleet and not a finite set of time-sequenced mission threads or effects chains.

3.8.1 Mission Thread Example

Deriving Multiple Surface Warfare Mission Threads from One Mission Architecture

Because the use of mission threads and effects chains has become ambiguous throughout the architecture community, an example is useful in understanding why CBMM encourages mission thread generation for analysis but not as a primary driver in development.

A surface action group (SAG) is typically defined as a grouping of surface vessels detached from a main force for a specific mission, using assets organic to or directly attached to any member surface platform. This may include helicopter assets, directly attached intelligence, surveillance, and reconnaissance (ISR) aircraft, or unmanned systems. Accordingly, a mission architecture used to model SAG operations for a given Fleet unit should include all activities conducted by each of these nodes. Not every excursion a SAG undertakes will simultaneously involve helicopters, ISR aircraft, and unmanned systems. Therefore, an architect can generate, from a comprehensive SAG mission architecture, individual mission threads that model how a SAG would use an ISR aircraft to increase fidelity of a targeting solution; another mission thread to show how unmanned systems can augment targeting capabilities; and a third mission thread to show how helicopters can work with unmanned systems to employ a coordinated air-to-surface attack on a surface target. Each mission thread contains its own unique deadlines, measures, and sequence of events; however, the relationships between activities executed by each performer are all derived from and are in compliance with a common SAG mission architecture.

This example demonstrates that a single mission architecture can lead to multiple mission threads. Similarly, by identifying the systems used to satisfy each activity in sequence, multiple effects chains can be generated to show the different ways performers may use material solutions to address an operational need. This example also shows how any single mission thread or effects chain only models a limited subset of the overall mission architecture, and that any single mission thread is insufficient for modeling end-to-end mission execution. Had the architecture been driven by a single thread or chain, the final mission architecture product may have omitted vital platforms, systems, or performers otherwise critical to overall execution of the mission area and achievement of larger Fleet capabilities.

3.8.2   Mission Thread Analysis Discovery of Capability Gaps

Using mission threads and effects chains to define critical measures and to communicate application of activities and systems to a mission can result in identifying and characterizing capability gaps. Many capability gaps are the result of poor technical requirements that manifest themselves as insufficient technical performance throughout mission execution. Since mission threads and effects chains combine systems and performers across programs and organizations to demonstrate how they support a mission, these threads and chains become effective communication mechanisms for gap demonstration and assessment.

Whether gaps are identified through assessment of threads and chains or whether they are known prior to developing the architecture, threads and chains can also serve an important role in identifying root causes and effects caused by deficiencies in critical measures. By using the critical measures and associated activities or functions as the focal point of a thread or chain, the architect can articulate the total mission impacts as a result of a specific measure value. When paired with M&S tools, these architectural models produce a blueprint for automated gap analysis.

3.9   Summary of Products and Supplemental Products

Table 1 lists all products identified as critical parts of CBMM and includes a list of optional viewpoints with their related data elements. These models are considered core to developing an architecture using a Fleet-first approach.

Table 1: CBMM Core Models

Modeling Phase	Viewpoint Acronyms and Names	Suggested Type	Data Elements
Summary and overview and scenario documentation	AV-1: Overview and Summary Information	Textual	All
	OV-1: High-Level Operational Concept Graphic	Graphic, textual	Capabilities, mission, desired effect, conditions, doctrine
Capability definition and mappings	CV-2: Capability Taxonomy	Node tree	Capabilities, mission, desired effect
	CV-4: Capability Dependencies	Functional model	Capabilities, mission, desired effect
	CV-6: Capability to Operational Activities Mapping	Functional model	Capabilities, measures
Activity models	OV-5a: Operational Activity Decomposition Tree	Node tree	Activities
	OV-5b: Operational Activity Model	Functional model	Activities, conditions, people and/or performers, measures
Operational context	OV-2: Operational Resource Flow Description	Varies	People and/or performers, platforms, resources
	OV-3: Operational Resource Flow Matrix	Matrix	People and/or performers, platforms, resources
	OV-4: Organizational Relationships Chart	Node tree	People and/or performers, platforms

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Modeling Phase	Viewpoint Acronyms and Names	Suggested Type	Data Elements
Technical mapping	SV-5a: Systems Function Traceability Matrix	Matrix	System functions, activities, resources, measures
	SV-5b: System Traceability Matrix	Matrix	Systems, activities, resources, measures
	SV-4: Systems Functionality Description	Varies	Systems, system functions
	SV-1: System Interface Description	Varies	Systems
Capability-system mapping	CV-5: Capability to Organizational Development Mapping	Matrix	Capabilities, systems, system functions (organizations are part of AV-1 stakeholders)
Optional "for purpose" models (used to answered questions documented in AV-1)	OV-6a: Operational Rules Model	Textual	Activities, doctrine
	OV-6c: Operational Event-Trace Description	Swim lane chart or objective model	Activities, conditions, people and/or performers, platforms, measures
	SV-2: Systems Resource Flow Description	Varies	Systems, resources
	SV-3: Systems-Systems Matrix	Matrix	Systems
	SV-10c: Systems Event-Trace Description	Varies	System functions, conditions, people and/or performers, platforms, measures

Note Table 1 omits the AV-2, which is required as a part of proper DoDAF 2.0 architecture development. The integrated dictionary is a core viewpoint in any integrated architecture but does not have CBMM-unique impacts and is therefore not included in the list of core or optional CBMM models. All mission architectures should comply with the guidance set forth by the DoD Chief Information Officer, regardless of the methodology pursued.

DoDAF 2.0 also contains numerous viewpoints not identified as part of the core CBMM model set that may be useful, depending on the specific objectives set forth in the AV-1. It is incumbent upon architects to determine which models are appropriate to obtain answers and to achieve goals established by each stakeholder.

4.0   IMPACTS ON MISSION ENGINEERING

Architectures are built for the purposes defined in the AV-1. These purposes should be used for analysis, assessment, evaluation, or requirements definition objectives that leverage the powerful data management schema inherent to any DoDAF architecture. Architectures provide a tool for managing data that can be leveraged for mission engineering assessments and evaluations, but only if mission engineering needs are clearly articulated upfront in the architectural design process.

4.1   Defining Mission Engineering

Mission engineering involves planning, analyzing, organizing, and integrating emerging operational concepts for specifying the end-to-end mission architecture attributes across the

DOTMLPF spectrum. These mission architectures inform the communities of interest involved in fulfilling mission needs statements and aid in the identification of how material and non-material entities contribute to the Fleet's overall desired effect of Fleet readiness.

Historically, requirements definition is delivered to technical stakeholders through a series of studies and reports that endeavor to translate Fleet needs into requirements statements. Engineers design to requirement statements, which are then integrated into the legacy Fleet enterprise. Since the technical community does not maintain a comprehensive, Navy-wide enterprise architecture that engineers can use to inform their development, the efficiency at which an emerging technology can be integrated with the Fleet becomes almost entirely dependent on the suitability of a program's requirements specifications. Past lessons in Navy acquisitions have shown this process can often result in the delivery of systems for operational testing or initial operational capability that fully support their design system requirements but fail to adequately perform mission functions essential for achieving the Fleet's desired effects.

Mission architectures provide a mechanism for managing data that allows the technical community to clearly understand the mission context in which a system will be expected to operate. By maintaining awareness of design impacts on overall mission capabilities, system requirements can evolve as threat and Fleet capabilities and tactics evolve. System requirements' evolution allows technical stakeholders the flexibility and knowledge to modify or adapt system designs to better anticipate problems with integration onto a platform, into a fleet, or in a specified mission.

## 4.2   Modeling and Tool Development Implications

An important purpose of architecture is the management and manipulation of data originating from numerous data sources and maintained in a commonly accessible database. By centrally managing multiple stakeholders' data, individual organizations or communities of interest can access data from other sources when they themselves do not have the ability to collect it. Culture is the challenge posed to the architect and organizations wishing to benefit from centralized and common data management. Development and analysis teams want to locally manage or store data related to their tools because that ensures an amount of control. What they benefit from in control they lose in configuration management with the sources from which the data originates. This cultural clash between central data management and a preference of local data control is one that risks limiting the benefits of architectures toward informing tool development, improving data exchange and coordination between organizations, and integrating available modeling tools to produce more comprehensive analysis.

4.2.1   Informed Tool Development and Control

Centrally managed data, by definition, allows data subscribers to easily determine whether the source data in their models are up to date and consistent with the larger enterprise. Because the data is actively maintained by data owners and architects, users can identify the pedigree of information they use to define behavior and events in their tools. By locally controlling data, the onus is placed on each development organization to ensure all data contained in their models are accurate for the current Navy enterprise. This onus translates into additional expense for the sponsoring organization and time lost from development and analysis tasks that must now be used for configuration management. Leveraging a mission architecture removes this onus on each individual development team, resulting in a higher focus on development and analysis and improved development cost efficiencies.

4.2.2 Improving Data Exchange and Cross-organization Coordination

When development organizations assume the responsibility of locally controlling information, they also assume the role of gathering and ensuring proper configuration control of all authoritative data (see Figure 16).
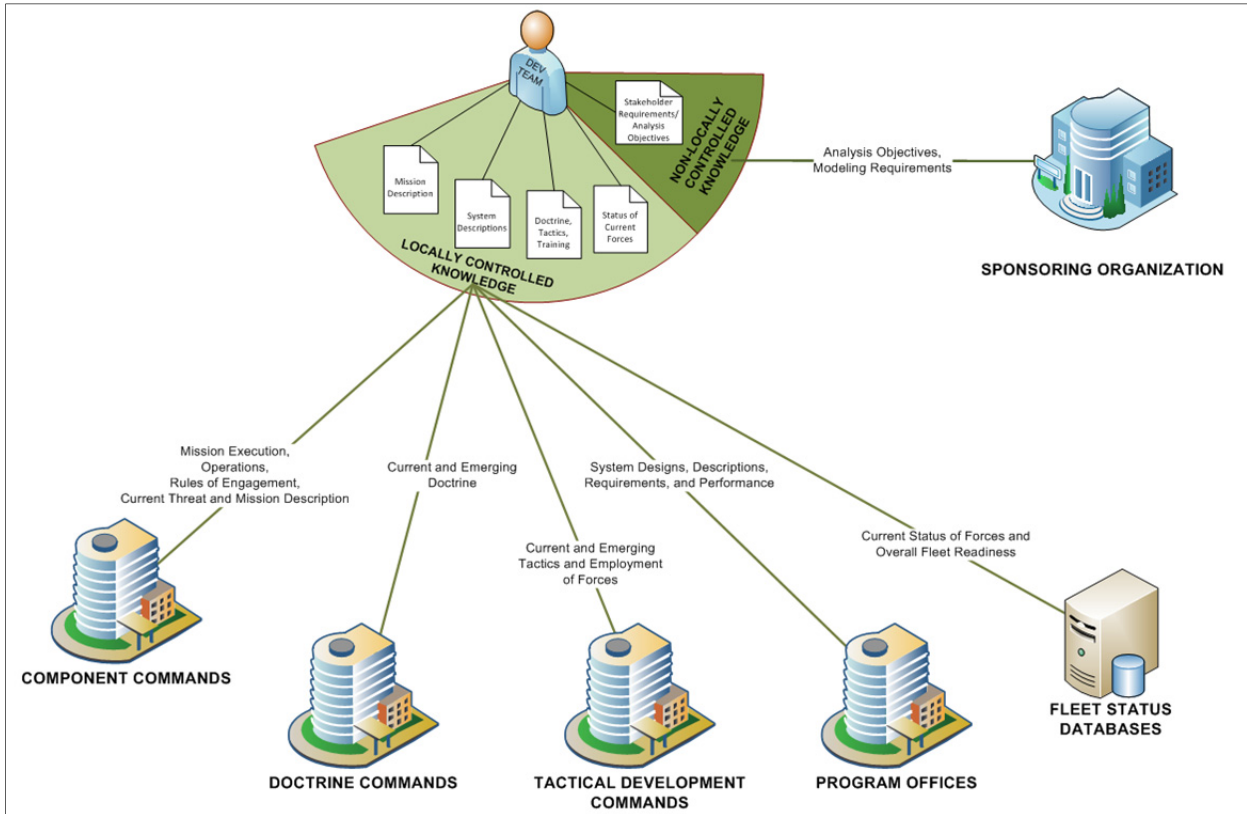

Figure 16: Individual Team Mapped to Data Required for Model Development

For a single development team and a single Fleet organization, this level of data exchange may seem trivial; however, Navy realities and complexities require multiple development teams to interact with numerous Fleet organizations to gather and exploit all information necessary to adequately address known operational deficiencies. As data sources, Fleet organizations are now tasked with responding to often similar or common data requests from numerous organizations, as illustrated in Figure 17. Responding to these requests can be both costly and divert Fleet organizations from their normal operational tasks. In some cases, Fleet organizations may become so overwhelmed they simply cease to answer redundant data requests.
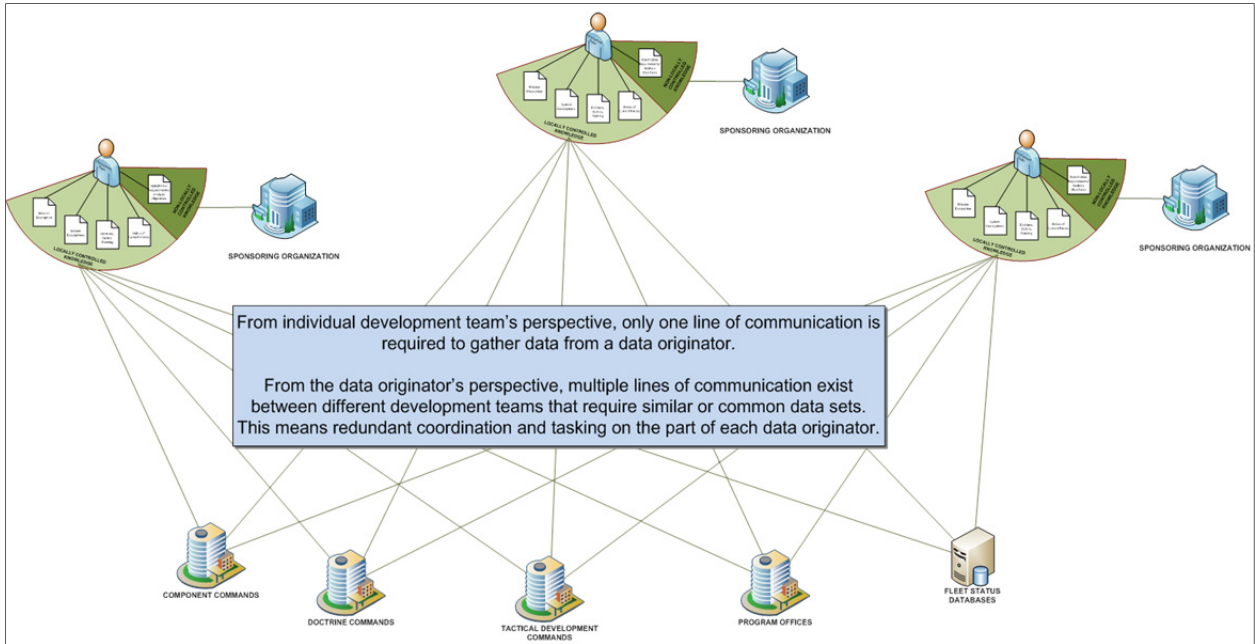
Figure 17: Network of Development Teams Interacting with Numerous Fleet Organizations

To alleviate requests for data on each data source and ensure no development teams are left without vital sources of validated Fleet data, architecture can be used to provide a single point of contact for both Fleet organizations and development teams as shown in Figure 18.
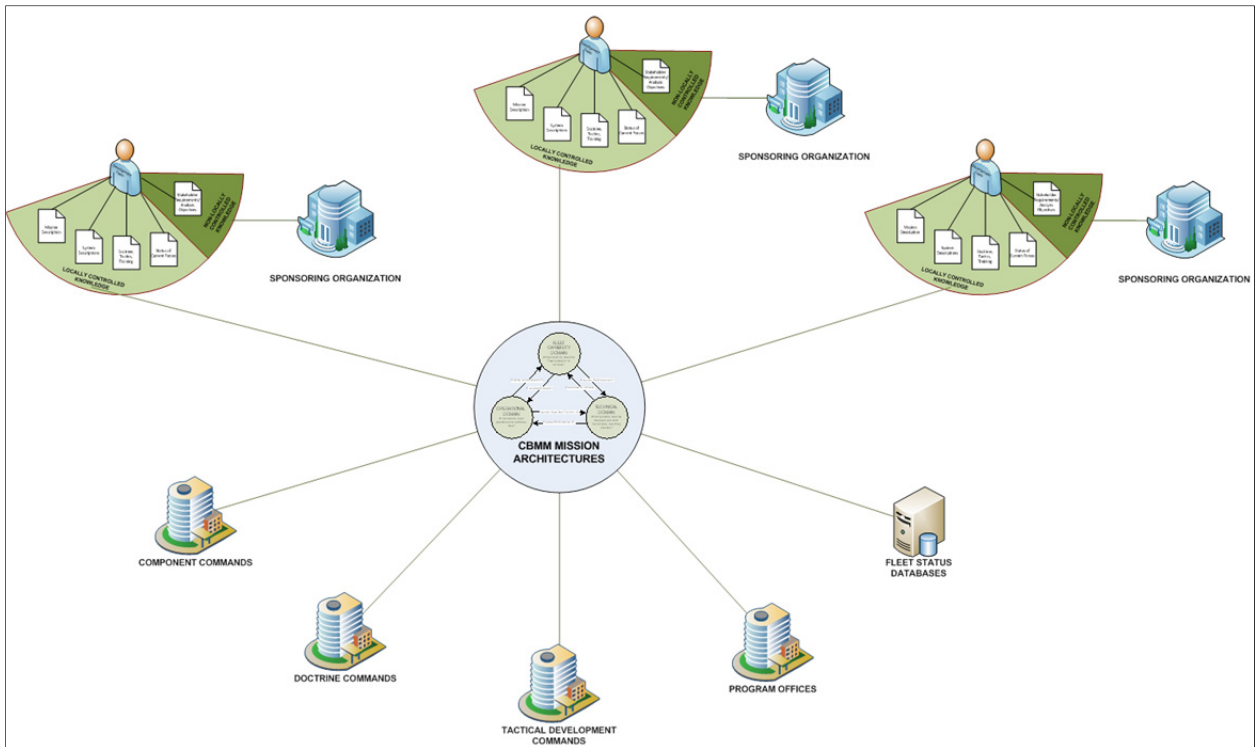
Figure 18: Improved Data Exchange Among Fleet Organizations, Data Originators, and Development Teams

The resulting enterprise brings improved data exchange to all stakeholders and reduces the need for redundant lines of communication between organizations.

4.2.3 Tool Integration

Coordinating modeling efforts can become complex. Often, development teams will process a list of analysis objectives and propose how their tool might address part or all of stated problems. Consolidating the strengths and weaknesses of each modeling team becomes complex and coordinating data dependencies between each individual tool to solve a common problem can lead to problems in what data are consumed, how they are processed, the assumptions under which each model is executed, and the conditions under which each model's output is valid.

Because architecture data is integrated per the CBMM data model, data needs also exist in an integrated nature. This allows engineers and analysts to more objectively identify how data should be exploited before selecting a tool to perform the required operation. Results can then be used to address analysis objectives or fed back into the architecture for dissemination to all relevant stakeholders.

This process, shown in Figure 19, is referred to as the Mission-to-Model process and includes developing architecture, planning data exploitation, executing exploitation strategies, developing comprehensive analysis, and updating architectural databases.
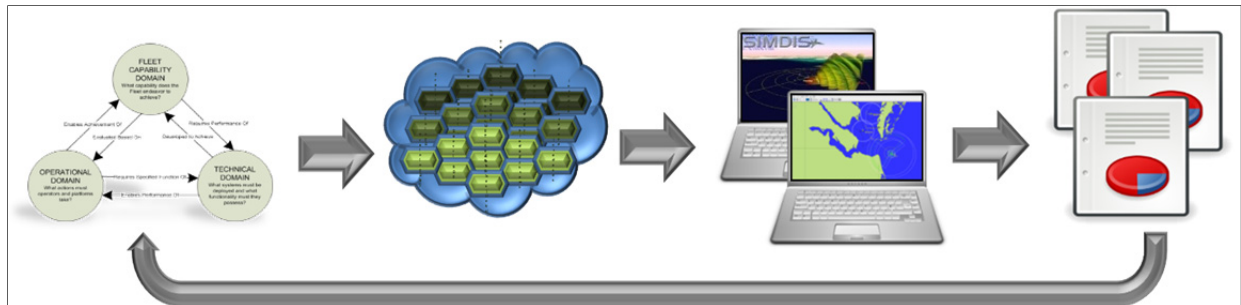

Figure 19: CBMM Mission-to-Model Process Graphic

4.3 Capability Gap Analysis

Identifying capability gaps is useful for all domains in the acquisition triad and is often performed by operational forces that have experienced degraded capabilities while executing training or operational missions. Architectures possess some limited ability to identify new capability gaps by establishing connectivity between operational activities required to achieve an overall desired effect and through identifying system-to-system functions that must be executed throughout the mission. By analyzing connectivity between activities and functions and the performance required of each data element, architects can identify when a particular activity or function is either not executed or executed under unsatisfactory conditions.

Architectures play a far greater role in aiding in the characterization and analysis of capability gaps. CBMM begins with identifying and establishing capabilities required to achieve the overall desired effect. All other architectural development is mapped into one or several initial capabilities, allowing the architect to clearly identify the causes and effects associated with a particular activity or function on higher level capabilities. By identifying a known capability gap, architects can isolate the activities and functions responsible for the specified capability, which aids in focusing analysis and M&S efforts required to assess and specify a solution for the gap. Likewise, analysis efforts that originate at the activity and system functional level can be mapped into known capabilities to determine if a modification to an individual operator, platform, or system generates a new potential gap.

4.4 Recommended Use and Appropriate Application of Mission Threads

Common use of mission threads, or OV-6a and OV-6c DoDAF models, has proven effective in commonly communicating architectural data across a wide audience, including non-technical audiences who only require a "big picture." Unfortunately, common use of mission thread models has also created an abundance of architectures that represent point-solutions resulting from driving architectural development from a single thread rather than a comprehensive study of all capabilities required to achieve a desired effect. For this reason, CBMM encourages the use of mission threads and effects chains for communication, collaboration, and validation but not as a means to drive development.

One such application is excursion modeling, or modeling of a single instantiation of how mission architecture may be executed given a set of initial conditions. Since excursions may vary greatly in their composition, scope, purpose, and other architectural factors, it is impractical for a generic architectural methodology to specify required and optional viewpoints. Each viewpoint selected for the excursion should be derived from the viewpoints contained in the parent architecture and selected based on the purpose of the excursion. The only requirement that CBMM places on generation of mission threads, effects chains (e.g., SV-10c viewpoints), or other architectural models is that they have a clearly defined purpose and reference the capability-driven mission architecture from which they are derived. CBMM recommends that all excursions mapped to a specific mission architecture be identified in AV-1 addendums. Placing excursion descriptions in an addendum avoids unnecessarily increasing AV-1 length and complexity but reinforces the role of the AV-1 to shape architectural development and clearly define analysis objectives.

The purpose for developing an excursion varies with each architecture product and stakeholder. Previous Navy I&I experiences have found excursions useful in characterizing capability gaps that only present themselves during specific operational conditions. Other experiences have found excursions useful in proposing and coordinating exercise planning with Fleet elements. The purpose and desired outcome of excursion development drives which viewpoints are created and to what level of fidelity each viewpoint must be developed.

5.0 SUMMARY AND CONCLUSIONS

CBMM is a capability-based modeling methodology that encourages architects to follow a Fleet-first approach for architectural development while accommodating data sources from across the Navy and greater DoD enterprise. Using CBMM ensures architectural development is appropriately scoped for the Fleet's overall desired effect and that causes and effects of a given action are clearly understood by stakeholders of all three domains represented in the acquisition triad. The central data management represented in CBMM products complements open data exchange and supports improved efficiencies in the collaboration and use of M&S tools. When used for data management purposes, CBMM architectures foster a greater level of awareness among Fleet leadership, operational units, and SYSCOMs, which accommodates development of DOTMLPF solutions to known and discovered capability gaps.

Architecture is a tool. Tools are composed of materials and designed for a purpose. DoDAF 2.0 provides the materials to build Fleet-first informational tools, and CBMM provides the design. By using CBMM to generate Fleet-first architectures, future acquisitions can be better informed by warfighters' needs, resulting in more efficient system deployment and force

integration. These improved efficiencies reduce overall Navy costs in acquisition, deliver better equipment to operational users, and ensure a more ready and complete Fleet force.

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