Information Capture During Early Front End Analysis in the Joint Capabilities Integration and Development System (JCIDS): A Formative Study of the Capabilities of the Department of Defense Architecture Framework (DoDAF)

by

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ABSTRACT

The United States has achieved defense superiority in air, land, and sea while using some of the most advanced defense systems in the world. However, underlying this success is a troubled procurement system. Enterprise-wide problems such as poor integration between the three components (JCIDS, DAS, PPBE) of DoD acquisition and inadequate management of procurement personnel have undermined the potential of the Department of Defense.

One particular area for improvement is the need for understanding the overlaps, gaps, and interdependencies of the capability portfolio. Information is a precondition to attaining that knowledge. Information is embodied in capability documents and architecture frameworks and drives the critical process of determining the right capability requirements upfront, a vital task in saving costs. (Wirthlin, 1994) The stakeholders need a comprehensive understanding of the capability portfolio during this validation process but information can be trapped in functional stovepipes.

DoD Architecture Framework (DoDAF) holds much promise in enhancing the visibility and traceability of information in the capability portfolio to the stakeholders. It is a more structured way to capture and analyze information than free-text documents. The most recent JCIDS manual published in February 2015 added a new requirement to submit seven DoDAF viewpoints during the ICD submission. This indicates the potential of DoDAF viewpoints to be able to provide a full representation of a capability requirement so it can be validated in light of a holistic understanding of the portfolio.

The purpose of this thesis is to analyze whether DoDAF alone can provide a holistic understanding of a capability requirement during this early front-end validation. The analysis examines the information captured by the viewpoints by comparing it to ICD information requirements. The results of the analysis reveal the benefits of DoDAF in its ability to capture more detailed information such as resource flows in structured form. A second finding revealed that the seven DoDAF viewpoints were missing key information elements about the capability requirement such as related missions and strategy documents that limit holistic visibility of the capability portfolio. Lastly, there were additional limitations such as the challenge of determining the level of specificity in the viewpoints. Recommendations include changing particular optional data fields to mandatory and adding the CV-1 and OV-3 viewpoints to provide more information about the capability requirement.

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Table of Contents

Acknowledgements 5

List of Figures 9

List of Tables 10

1. Introduction 12
1.1 Background 12
1.1.1 Acquisition in the Department of Defense 12
1.1.2 Joint Capabilities Integration and Development System (JCIDS) 16
1.2 Thesis Overview 18
1.2.1 Scope 18
1.2.2 Research Objective 20
1.2.3 Thesis Outline 20
1.2.4 Key findings 21

2. Literature Review 23
2.1 Systems Thinking 23
2.2 Enterprise Architecture 25
2.3 DoDAF-based Architecting 27

3. Understanding JCIDS 29
3.1 Enterprise Landscape 29
3.1.1 External Landscape 29
3.1.2 Internal Landscape 32
3.2 Background of the Stakeholders 34
3.2.1 Sponsors 34
3.2.2 Gatekeeper 35
3.2.3 Analysts 35
3.2.4 Validation Leadership (FCB leadership and the JROC/JCB) 36
3.3 Capability Portfolio Management Processes 37
3.4 Knowledge Elements – Initial Capabilities Document (ICD) and DoDAF 41
3.4.1 Background on the Initial Capability Document (ICD) 42
3.4.2 Background on the DoD Architecture Framework (DoDAF) 46

4. Assessing Available Information in DoDAF 52
4.1 Information requirements of the JCIDS Stakeholders 53
4.2 DoDAF Viewpoints Required with the ICD Submission 56
4.2.1 The Operational Viewpoints at the ICD stage 59
4.2.2 The Capability Viewpoints at the ICD stage 64
4.2.3 Summary 67
4.3 Alignment between the ICD and DoDAF 68
4.3.1 Available Information in DoDAF 70
4.4 Limitations of DoDAF 71
4.4.1 Misalignment between the ICD and DoDAF Viewpoints at the ICD-stage 73
4.4.2 Misalignment between DoDAF and the CML 79
4.4.3 Too Much Information or Not Enough? 81
4.4.4 What is a Capability? 82
4.4.5 Summary 84

5. Conclusion **86**
5.1 Recommendations **89**
5.2 Limitations and Future Work **91**
Appendix A: Past Successful Acquisition Programs in the Department of Defense **93**
Appendix B: Key Concepts of General Systems Theory **94**
Appendix C: Capability Mission Lattice **96**
Appendix D: Stakeholder Decomposition **97**
Appendix E: DoDAF-ICD Full Matrix **98**
Appendix F: DoDAF-ICD Matrix (Aligned Information) **99**
Appendix G: DoDAF-ICD Matrix (Partially Available Information) **100**
Appendix H: DoDAF-ICD Matrix (Unavailable Information) **101**
Bibliography **102**

List of Figures

Figure 1: RGS and JCIDS Comparison. Adapted from: (Wills, 2012) 17
Figure 2: DoD Acquisition System. Source: (U.S. Government Accountability Office, 2014) 31
Figure 3: Overview of Resource Allocation and Interaction with PPBE. Source: (US Department of Defense, 2015) 31
Figure 4: System Acquisition Framework. Source: ("System Acquisition Framework," n.d.) 32
Figure 5: Acquisition Management System. Source: (Davis et al., 2008) 38
Figure 6. JCIDS Process Lanes. Source: (US Department of Defense, 2015) 38
Figure 7. JCIDS Staffing Overview. Source: (US Department of Defense, 2015) 39
Figure 8. Hierarchical JCIDS Functional Architecture. Source: (US Department of Defense Joint Staff, 2015) 40
Figure 9: Basic Ontology of Notional F-22 ICD and Notional F-35 ICD. Source: (Ahmed, 2014) 45
Figure 10: The Evolution of the Architecture Framework. Source: (Dam, 2015) 47
Figure 11: Depiction of Models, Data, Views, and Viewpoints. Source: (Dam, 2015) 48
Figure 12: DoDAF Viewpoints. Source: (US Department of Defense, 2015) 49
Figure 13: DM2 CDM Core Concepts. Source: (DoD Deputy CIO, n.d.-c) 51
Figure 14: A Spectrum of Information Structuring. Source: (DoD Deputy CIO, n.d.-e) 52
Figure 15: The Connection Between the CBA and Capability Requirement Documents. Source: (US Department of Defense, 2015) 56
Figure 16: OV-5a Data fields. Source: (Deputy Director Cyber and C4 Integration, 2015) 58
Figure 17: OV-1 Example. Source: ("2.8. Technology Development Strategy/Acquisition Strategy (TDS/AS) Outline," n.d.) 60
Figure 18: Graphical OV-2 of a Notional Ground Vehicle 61
Figure 19: Graphical Depiction of an OV-4 for a Notional Ground Vehicle 63
Figure 20: Graphical OV-5a for a Notional Ground Vehicle 64
Figure 21: Graphical CV-2 for a Notional Ground Vehicle 65
Figure 22: Matrix CV-6 for a Notional Ground Vehicle 67
Figure 23: Aligned Information Between the ICD and DoDAF 70
Figure 24: Matrix of Optional or Unstructured Information 74
Figure 25: Matrix of Information that Require Multiple Viewpoints 76
Figure 26: Possible Links Between Different Categories of Capabilities When Using Multiple Viewpoints 77
Figure 27: Matrix of Information that Require Multiple Viewpoints or Additional Guidance 78
Figure 28: Information Alignment between the CML and DoDAF 80
Figure 29: Capability Mission Lattice 96
Figure 30: Stakeholder Decomposition 97
Figure 31: DoDAF-ICD Full Matrix 98
Figure 32: DoDAF-ICD with Aligned Information 99
Figure 33: DoDAF-ICD with Partially Available Information 100
Figure 34: DoDAF-ICD Matrix with Unavailable Information 101

List of Tables

Table 1: Certification and Endorsement Responsibilities. Source: (US Department of Defense, 2015) 37
Table 2: Joint Staff Sections Responsible for ICD sections. Source: (US Department of Defense, 2015) 41
Table 3: ICD Content. Source: (US Department of Defense, 2015) 43
Table 4: Key OV-2 Data Fields. Source: (Deputy Director Cyber and C4 Integration, 2015) 61
Table 5: Key OV-4 Data Fields. Source: (Deputy Director Cyber and C4 Integration, 2015) 62
Table 6: Key OV-5a Data Fields. Source: (Deputy Director Cyber and C4 Integration, 2015) 64
Table 7: Key CV-2 Data Fields. Source: (Deputy Director Cyber and C4 Integration, 2015) 65
Table 8: Key CV-3 Data Fields. Source: (Deputy Director Cyber and C4 Integration, 2015) 66
Table 9: Section 4.2 Summary 68
Table 10: The Number of Data Fields in Each Viewpoint. Source: (Deputy Director Cyber and C4 Integration, 2015) 69
Table 11: Operational Context Described by the ICD and DoDAF 73
Table 12: Descriptions of a Capability and Capability Requirements 84
Table 13: Summary of Key Findings 85
Table 14: Past Successful Acquisition Programs. Source: (Davis et al., 2008) 93

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1. Introduction

"I reject the notion that we have to waste billions of taxpayers dollars to keep this nation secure."
- Barack Obama

1.1 Background

1.1.1 Acquisition in the Department of Defense

The United States has achieved defense superiority in air, land, and sea while using some of the most advanced defense systems in the world. However, underlying this success is a troubled procurement system.

> *Although the current processes have produced the best armed forces in the world, they do not optimize our investment in joint capabilities to meet current and future security challenges. (Joint Defense Capabilities study 2004)*

The US Department of Defense (DoD) has struggled with this ineffectual acquisition system since its auspicious start with the National Security Act of 1947. (Converse, 2012) Despite the increasing need for improved weapons systems in the midst of imminent and existing threats, the acquisition system has largely been defined by cost overruns, schedule slippages, and project cancellations.

This is not to say that there have not been successful developments. Table 14, compiled by RAND, contains examples of effective programs that have greatly benefited the joint force. The report found that the main contributor to their success was that they were accomplished "outside the mainstream bureaucratic processes of the time". (Davis et al., 2008) Unfortunately, these successes have not been the norm.

Forty years after the creation of the DoD, it still grappled with inter-service rivalry, weakened civilian authorities, and an unclear chain of command. Each service was determining their own requirements and developing their own systems, which caused an inefficient use of resources. Congress ultimately questioned the DoD's ability to deliver strategic and operational value so they crafted the Goldwater-Nichols Act of 1986, arguably the most far-reaching defense reform to date. (Murdock & Weitz, 2004) The objectives of the legislation were clear:

> *Congress sought to strengthen civilian authority within the Department, improve military advice to civilian leadership, clarify the authority and responsibilities of the Combatant Commanders (CoComs, formerly known as "CINCS"), improve strategy formulation and contingency planning, provide for more efficient use of defense resources, and enhance the professionalism and personnel management of the joint officer. (Murdock & Weitz, 2004)*

This began the move for the DoD from a service-focused organization to a more joint organization to increase overall effectiveness. However, a capable resource procurement system was still an unmet goal twenty years later. A 2007 House Armed Services Committee's report states:

> *Simply put, the Department of Defense (DOD) acquisition process is broken. The ability of the department to conduct the large-scale acquisitions required to ensure our future national security is a concern of the committee. The rising costs and lengthening schedules of major defense acquisition programs lead to more expensive platforms fielded in fewer numbers. (Committee, 2006)*

Congress's dissatisfaction led to a unanimous vote in support of the Weapons Systems Acquisition Reform Act, which President Obama signed in 2009. (Augustine et al., 2009) Secretary of Defense Gates also highlighted glaring shortfalls while testifying at the Senate Armed Services Committee in 2009:

> *Entrenched attitudes throughout the government are particularly pronounced in the area of acquisition: a risk-averse culture, a litigious process, parochial interests, excessive and changing requirements, budget churn and instability, and sometimes adversarial relationships within the Department of Defense and between DOD and other parts of the government. (Gates, 2009)*

A GAO report in FY 2010 reported that 98 Major Defense Acquisition Programs (MDAP) recorded over $402 billion of cost overruns and an average of 22 months of schedule slippage. (Berteau et al., 2010) In a decade, the Army alone spent over $30 billion on programs that were not useful or never reached the Soldier on the battlefield. (Erwin, 2015) In 2015, the departing Army Secretary John McHugh still considered the struggling acquisition system as an intractable problem. "When I came in, I hoped to have the problem solved. The issue is that you never solve it, you're always chasing." (Erwin, 2015) These issues with the larger acquisition enterprise have been well documented over the years:

1. There is poor integration between the three components of the larger DoD acquisition system: Joint Capabilities Integration and Development System (JCIDS), Defense Acquisition System (DAS), and Planning, Programming, Budgeting, and Execution (PPBE). Operational, economic, and technological factors are accounted for separately when they should be better integrated. (Davis et al., 2008)

2. Funding instability creates an uncertainty in projects. Even though a project is on schedule, the unpredictable budget has caused programs like the Ground Combat Vehicle (GCV) to be undermined and cancelled.

3. Capability concepts based on immature technologies inflate the risk of cost overruns and schedule delays. In addition to unrealistic requirements, "requirements creep" or "the unplanned addition of capabilities to a program that exceed the requirements originally identified" has also been cited as a major problem. These additional requirements can come from agencies and branches of the military that are not responsible for the success of the program. (Bean et al., 2014)

4. Procurement personnel are not adequately trained and do not have the skills to manage the complexity of acquiring materiel systems in an unstable budgetary environment. Also, the acquisition career path is less appealing than the operational positions, which results in attracting less talent to the acquisition workforce. (Bean et al., 2014)

5. The acquisition managers have no incentives "to say that their program is not progressing well, it is not worth the money, and should be slowed or cancelled." (Bean et al., 2014) They also do not spend enough time in the position to see a successful deployment of a materiel system or even a milestone. Thus, they are not held accountable for any failures.

6. There are too many overseers, decision makers and regulations, creating a slow, risk-averse culture. There are over 40 decision makers for low priority acquisition programs. (Fast, 2010) The Packard Commission study in 1986 discovered that bureaucracy and oversight created too much distance between the warfighter's needs and capability requirements but it has not improved since. (Cherry, 2010)

There has been a wide range of recommendations to meet these challenges within the DoD acquisition system. Some advocate a cultural shift that incentivizes cost control, encourages innovation, and retains higher quality workforce. (GAO, 2015; Schwartz, 2014) Other recommendations include better integration between JCIDS, PPBE, and DAS while getting senior leaders involved early in the requirements process and stopping technological over-reach. (Cherry, 2010; GAO, 2015)

There have been multiple reforms that have taken place to improve the acquisition enterprise. However, the major changes have largely been ignored. (Wirthlin, 2009) And the incremental changes as a result of these reforms have proved unfruitful in improving cost control and producing timely developments. (Schwartz, 2014) Secretary of Defense Gates noted in the aforementioned Senate hearing, "Since the end of World War II, there have been nearly 130 studies on these problems – to little avail." (Gates, 2009)

Instead the regulatory environment increasingly grew in complexity. The Armed Services Procurement Regulation (ASPR) initially started with 125 pages in 1947. Additional volumes were added and increased the page count to more than 2,000 pages, which excluded service-specific regulations. There are also mandatory policies outlined in the DoD Directive (DoDD) 5000 series regarding the acquisition process. This series was first signed in by Deputy Secretary of Defense Packard in 1971 and has since gone through 14 major revisions. (Cherry, 2010) The DoDD 5000 series began as an eight-page document and grew to almost 900 pages in 1991. This has since been reduced to 90 pages. (Fox, 2011) This is in addition to the Code of Federal Regulations, which amounted to 180,000 pages in 2011. (Bean et al., 2014)

There have been recent changes to decrease the burdensome bureaucratic oversight. Former Army Chief of Staff, General Ray Odierno, pushed for more involvement of the service chiefs throughout the procurement process instead of consigning them to just the front end requirements step. (Freedberg, 2016) More authority was transferred to the military in the 2016 National Defense Authorization Act, which increased the decision making power of the service chiefs for non-joint or OSD level programs. (Johnson, 2015) Additionally, the new Army Chief of Staff, General Mark Milley is advocating for scaling back OSD oversight over technology readiness level certification, testing determination, independent cost assessment (ICE), and analysis of alternative approvals. (Freedberg & Clark, 2016)

1.1.2 Joint Capabilities Integration and Development System (JCIDS)

In 2001, Secretary of Defense Rumsfeld made a fundamental shift to a capabilities-driven approach to planning rather than a threat-based approach. He writes in the 2001 Quadrennial Defense Review:

> *A central objective of the review was to shift the basis of defense planning from a "threat-based" model that has dominated thinking in the past, to a "capabilities-based" model for the future. This capabilities-based model focuses more on how adversaries fight, rather than specifically whom the adversary might be or where a war might occur. (Office of the Secretary of Defense, 2001)*

However, the requirements system still operated as service-centric system that validated and developed solutions that were not integrated with the rest of the overarching force. The capability solutions and requirements were redundant and unrealistic. (Bean et al., 2014) They were also not prioritized and analyzed properly which continued to lead to exorbitant expenses. The left process in Figure 1 depicts this service-centric process of determining requirements. In 2002, Secretary of Defense Rumsfeld wrote to the Chairman of the JROC General Pace:

> *As Chairman of JROC, please think through what we all need to do, individually or collectively, to get the requirements system fixed. It is pretty clear it is broken, and it is so powerful and inexorable that it invariably continues to require things that ought not be required, and does not require things that need to be required. (JCS J-8, 2009)*

The JCIDS was created in 2003 in response to this as part of the continual evolution to more "jointness" and was fully implemented in 2009. JCIDS is meant to review and validate requirements from the perspective of joint capabilities to eliminate redundancies and improve integration and interoperability of a joint force. (Ryder & Flanigan, 2005) The right side of Figure 1 captures the new requirements determination of JCIDS. In 2003, the Joint Staff J-8 also developed 21 Joint Capability Areas (JCA) to further refine "joint" language to clarify the capability categories along functional lines to perform capability-based planning.

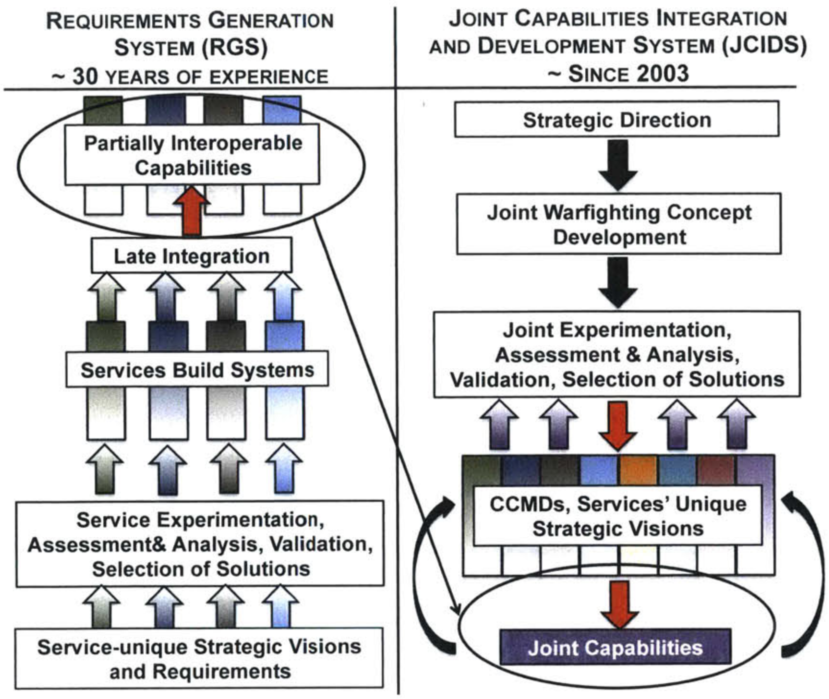

Figure 1: RGS and JCIDS Comparison. Adapted from: (Wills, 2012)

Although JCIDS is a major step towards more "jointness" the challenges still remain. The advent of JCIDS created an even more complex requirements enterprise that is too time consuming to support the warfighter and poorly integrated with PPBE and DAS. (Augustine et al., 2009; Cherry, 2010; Davis et al., 2008) A major revision to the process was implemented on March 2009 to address deficiencies and streamline the process. A 2012 revision was meant to prepare for a stricter budgetary environment. The latest revision in January 2015 included more details on aligning affordability and the capability requirements documents. (Ahmed, 2014)

A Defense Acquisition Performance Assessment (DAPA), commissioned by Acting Deputy Secretary of Defense Gordon England, and interviews conducted by Wirthlin in his PhD dissertation revealed similar JCIDS specific issues:

1. The JCIDS process does not formerly account for interdependencies or redundancies between existing capabilities, capabilities in development, approved capabilities for development or capabilities developed at the service level. (Wirthlin, 2009)
2. There is "lots of process for process sake" with too many mandatory steps of coordination with increased uncertainty of rejection. (Bayer et al., 2008; Wirthlin, 2009)

3. The process is too long. The preparation of an ICD or an analysis of alternatives (AoA) usually can take over a year for major capability requirements that are ACAT 1, during which funding and operational priorities may change the capability requirements. (Wirthlin, 2009)

4. There is a divide between the acquisition personnel and the end user, resulting in unrealistic capability requirements.

1.2 Thesis Overview

"Two conditions must come together in order for knowledge to exist. The first is accuracy (representing things as they are), and the second is having appropriate thought and experience upon which one's conclusion (representation) is based. When these two factors are present, knowledge is attained." (Willard & Black Jr., 2014)

1.2.1 Scope

The beginning is the most important part of the work.
- Plato, 4th century B.C. (Rechtin & Maier, 2009)

The challenges facing the larger Acquisition enterprise cannot be solved with only tangential improvements but rather holistic approaches. There have been other research efforts that undertook this nontrivial task of transforming the enterprise. (Augustine et al., 2009; Kadish et al., 2006) They sought to address the complexity of developing and delivering capabilities to the warfighter while being couched in a dynamic political, fiscal, and threat environment. This thesis, however, will focus on the early stages of JCIDS and the challenge of determining the right capability requirements upfront, a vital task in saving costs. (Wirthlin, 1994)

The importance of thoroughly investigated upfront requirements in architecture design is commonly understood. Bachmann et al. describe how the "the initial stages of architecture design are where the most fundamental design decisions are made; these are the decisions that are the most difficult to correct when they are in error." (Bachmann et al., 2000) Although this is in reference to software architecture, this principle is applicable to many fronts. There will undoubtedly be adjustments later on in the life cycle. Indeed, a common architecting principle is that "You can't avoid redesign. It's a natural part of design." (Rechtin & Maier, 2009) However, a quality requirements process upfront will help mitigate the costly fundamental errors during the production stage. (Gause & Weinberg, 2011)

One particular area for improvement in the early requirements stage of the JCIDS process is information being trapped in functional stovepipes, which hinders the stakeholders' overall understanding of the overlaps, gaps, and interdependencies of the capability portfolio. Information is a precondition to attaining this knowledge about the portfolio. This information is embodied in capability documents and architecture frameworks and drives the critical process of determining the right capability requirements upfront, a vital task in saving costs. (Wirthlin, 1994) The question is whether this information is visible and traceable to the stakeholders who need a comprehensive understanding of the capability portfolio during this validation process.

DoD Architecture Framework (DoDAF) holds much promise in enhancing the visibility and traceability of information in the capability portfolio to the stakeholders. It can be a more structured way to capture and bring order to the complexity of a capability portfolio than free-text documents like the ICD. There has been a growing body of literature claiming the benefits of an architecture-based approach to designing systems at all stages of the lifecycle. The Joint Staff is also realizing its potential and has made DoDAF products a mandatory portion of all capability requirement submissions. The most recent JCIDS manual published in February 2015 added a new requirement to submit seven DoDAF viewpoints during the ICD submission. This implies that these DoDAF viewpoints have the potential to aid the stakeholders in fully understanding a capability requirement so it can be validated in light of a holistic understanding of the portfolio.

The scope of this thesis will be here. It will examine the extent to which DoDAF can provide this information during the ICD-stage, the front-end of the JCIDS process when the initial set of stakeholder needs are agreed upon by all involved and validated by the Joint Staff authorities.

1.2.2 Research Objective

The primary research question for this thesis is:

What are the capabilities and limitations of DoDAF during the ICD stage of validating a capability requirement?

The purpose of this thesis is to analyze whether DoDAF can provide a holistic understanding of a capability requirement during this early front-end validation. This research will examine the alignment between the information captured by the viewpoints and the ICD information requirements during the ICD stage before the capability is instantiated by physical systems.

The underlying assumption is that a structured architecture framework such as DoDAF will allow faster queries and quicker access to information about capability requirements than reading documents. Although, currently, DoDAF is used in conjunction with other information sources such as capability documents and past studies, it can potentially be used as the sole source of accessible information. A comparison between these two methods is worthwhile but outside the scope of this thesis. Instead, it will focus on the captured information and whether it is traceable and visible in the joint capability portfolio rather than the use of DoDAF.

1.2.3 Thesis Outline

This thesis will begin with a literature review on systems thinking, enterprise architecture, and architecture-based analysis. The following chapter will describe the JCIDS enterprise and its current capabilities and challenges. This will set the foundation for how DoDAF applies to the stakeholders in JCIDS, which is discussed in Chapter 3. It will begin with a background of DoDAF and ICD and examine the extent to which its information can support decision-making during the validation process. The thesis will conclude with recommendations for future work.

1.2.4 Key findings

The results of the analysis reveal the benefits of DoDAF in its ability to capture more detailed information such as resource flows in structured form. DoDAF can capture an unlimited amount of information about a single capability requirement through its flexible data fields and non-prescriptive nature. This can provide stakeholders a very full understanding about the single capability requirement in isolation.

However, it is difficult to apply systems thinking and develop a holistic understanding of the complexity when there are differing capability requirement architectures in the capability portfolio. One can certainly use DoDAF to create enterprise level architectures to conduct this analysis. Applying prior experiential knowledge or accessing additional studies can also reveal the linkages between key features such as missions, operational activities, and operational attributes. These linkages, however, are not readily available with the DoDAF viewpoints required at the ICD-stage. Table 13 depicts the main limitations from the findings.

Recommendations include providing standard guidance in capturing capability gaps/overlaps, threat capabilities, non-materiel capabilities and enabling capabilities with multiple viewpoints or utilizing the "capability type" data field. Currently, this information is only contained in the ICD. Furthermore, the addition of the CV-1 and OV-3 would provide a fuller picture of the capability during front-end analysis of the JCIDS process. This would enable the stakeholder to answer questions like what other capabilities can partially deliver a particular effect or operate in certain conditions. Currently, this information would not be in the architecture repository for JCIDS at the ICD-stage. This information in aggregate would increase the information aligned with the ICD from 4 to 10 information elements. This decreases the need to solely rely on sifting through capability documents to determine traceability to information such as missions, conditions, or desired effect. Instead, more of the analysis can be based on knowledge repositories with DoDAF architectures.

Although these recommendations are not a panacea to the problems facing the DoD acquisition enterprise, it can be a step towards unlocking more information about the capability requirement contained in unstructured texts to be able to conduct more thorough and quicker analyses by the stakeholders.

2. Literature Review

This section begins with a review of systems thinking as the theoretical basis for enterprise architecture. The following section describes the concepts in enterprise architecture, which will be used in describing the JCIDS enterprise and in investigating the utility of DoDAF in the ICD stage. Section 2 concludes with recent literature about JCIDS and DoDAF.

2.1 Systems Thinking

An examination of a capability requirement and its complex environment, in the broadest sense, is grounded in systems theory. Capabilities and the operational environment are becoming increasingly complex and require a holistic approach to understanding. In the early 20th century, thinkers like Norbert Weiner, Ludwig von Bertalanffy, and William Ross Ashby advanced the notion that complex systems need to be studied holistically by taking into consideration the technical and social factors that are distinct from its parts. (Leveson, 2011) (Bertalanffy, 1968, 1972) Key concepts such as an open system view, system boundaries, and subsystems were captured under what became to be known as General Systems Theory. (Kast & Rosenzweig, 1972) See Appendix B: Key Concepts of General Systems Theory for key concepts. They looked at the world as being comprised of systems, which contain interdependent parts that interact with each other and with those outside the system. (Boulding, 1956) (Haskins, Forsberg, Krueger, Walden, & Hamelin, 2011) (Vesely & Goldberg, 1981)

A reductionism approach became inadequate as systems became more complex. Leveson mentions four different forms of complexity that systems face: "interactive complexity (related to interaction among system components), dynamic complexity (related to changes over time), decompositional complexity (where the structural decomposition is not consistent with the functional decomposition), and nonlinear complexity (Where cause and effect are not related in a direct or obvious way)." (Leveson, 2011) The increasing number of interactions between elements, the often-immeasurable human factor, and the emergent behavior of the system could not be fully explained by the traditional scientific method alone. Mere intuition or experience was also insufficient to conceptualize the effects of a decision on the entire system. (Simon, 1979, 1982; Perrow, 1984; Forrester 1961) (P. M. Senge & Sterman, 1992) (Thomke & Manzi, 2014)

By contrast, systems thinking takes a holistic approach to examine the complexity of systems. (Ackoff, 2004) Peter Senge writes how systems thinking is "[t]he discipline for seeing wholes.... Today we need systems thinking more than ever because we are being overwhelmed by complexity.... Systems thinking is a discipline for seeing the structures that underlie complex situations." (P. Senge, 1990) This practice in turn becomes much more interdisciplinary as the need to view problems from multiple perspectives increases with complexity (Morgan 1997).

This systems approach inevitably led scholars in other fields to study complex problems from a systems perspective as well. One can find a systems paradigm in as diverse subject areas as child protection to urban street gangs to military strategy. (Munro, 2005) (Ruble & Turner, 2000) (Baker, 2006) (Allen, Cunningham, Army, & College, 2010; Cunningham & Allen, 2012; Gregory, 2010)

Additionally, systems thinking has underpinned studies on enterprises. One could argue that the enterprise is the most complex system that exists. Using Boulding's nine levels of complex systems, Hoogervorst classifies the enterprise as the second most complex behind transcendental systems. (Boulding, 1956; Hoogervorst, 2009)

Much of the literature regarding enterprises mainly takes an Information Technology perspective. (Rhodes et al., 2009) However, some have recognized the need for a more holistic definition as organizations become more integrated with numerous systems. Similar to the definition of systems, Rebovich from MITRE defines the enterprise as "an entity comprised of interdependent resources (e.g., people, processes, organizations, technology, funding) that interact with each other (to, e.g., coordinate functions, share information, allocate funding) and their environment to achieve goals." (Rebovich, 2006) Similarly, Nightingale and Rhodes define enterprises, as "complex, highly integrated systems comprised of processes, organizations, information and supporting technologies, with multifaceted interdependencies and interrelationships across their boundaries. Understanding, engineering, and managing these complex social, technical, and infrastructure dimensions are critical to achieving and sustaining enterprise performance." (Nightingale & Rhodes, 2004) The military certainly qualifies as a complex enterprise.

Because of the larger number of considerations in enterprises, there is a growing body of literature that advocates the need for a holistic systems approach that takes into account the cross-departmental nature of enterprise-level challenges. A framework that only focuses on IT and business strategy excludes influential drivers within the enterprise that must be part of the solution. Many advocate systems thinking as a proper approach in analyzing an enterprise's complex problems. (Lapalme, 2012; Gotze, 2013)

2.2 Enterprise Architecture

The concept of an architecture lends itself well to systems thinking. Graves defines an architecture "as the structure of components, their interrelationships, and the principles and guidelines governing their evolution and design." (Graves, 2009) He continues to express that it "defines the content for a 'knowledge base' about structure, components, interrelationships and principles that are relevant to the needs of the enterprise."

Architectures are utilized in fields that range from software to enterprises, all of which emphasize different aspects of knowledge. Architectures are useful in depicting process flows, gaps, principles, design concepts, connectivity, and other aspects of a complex system that are difficult to systematically envision without getting information overload. (Group, 2001) These essential elements of an enterprise are mainly communicated through architecture frameworks that holistically capture information about the multiple dimensions of the enterprise. (Russell, 2005) The framework provides a frame of reference or common understanding through shared models and viewpoints that convey information such as its structure, context, constraints, functions and goals. Not unlike a blueprint of a building, an architecture framework is more or less a static depiction of a system. However, an architecture framework for a system allows the ability to take into consideration the dynamic aspect and design for change. Thus, enterprise architecture can be thought of as "a discipline through which an enterprise can identify, develop and manage its knowledge of its purpose, its structure and itself." (Graves, 2009)

There are a variety of frameworks that encompass viewpoints to communicate a specific aspect of the enterprise. Urbaczewski and Mrdalj compare five frameworks from a software development perspective. (Urbaczewski & Mrdalj, 2006) They cover the Zachman Framework, Department of Defense Architecture Framework (DODAF), Federal Enterprise Architecture Framework (FEAF), The Open Group Architectural Framework (TOGAF), and the Treasury Enterprise Architecture Framework (TEAF). They compare the abstractions of each framework to see which products are emphasized. For example, DODAF includes information about the people within the architecture through organizational relationships while TOGAF provides that information in its IT resource guidance and FEAF doesn't include personnel information at all. They conclude that the Zachman Framework is the most comprehensive in its views and compatibility with the five phases of the Systems Development Life Cycle.

Schekkerman also provides a break down of various enterprise architecture frameworks to provide the reader information on choosing the most applicable framework to his or her domain and group of stakeholders. (Schekkerman, 2004) His approach is less IT-centric and provides a broader background of enterprise architecture frameworks in addition to discussing metrics and principles.

These frameworks when couched in systems thinking can highlight the complex interactions within the enterprise without becoming too static with excessive details. Peter Bernus distinguishes between 'heavy' and 'light' frameworks. (Gotze, 2013) 'Heavy' architecture frameworks are very in-depth and contain detailed content. This can be useful for understanding the interdependencies and complexity within an enterprise. A heavy architecture may be unnecessary if the goal was to just understand the structure at the enterprise level.

"Developing a complete enterprise model of every element in the organizational value net is a daunting task… comprehensive definition is better done outside of the scope of the Enterprise Architecture effort. The level of enterprise architectural detail should be governed by the overall objectives of collaboration alignment, validation and the ability to implement and assess risk". (Schekkerman, 2004)

Instead, Bernus advocates for 'light' frameworks that are conceptual and broadly applicable across dynamic domains. This allows the stakeholders within the enterprise to identify leverage points to influence and adapt to change while avoiding system "traps" (Gotze, 2013)

This thesis examines the level of architectural detail possible with DoDAF if it was used as the sole information source for analyzing a capability portfolio. Structured enterprise architecture frameworks such as DoDAF could provide stakeholders a much faster and comprehensive way of analyzing a capability requirement than free text documents.

2.3 DoDAF-based Architecting

Architecting has been a useful preamble activity to designing for a system with enterprise-wide effects. Many studies assert the benefits of enterprise architecture to an organization. They are known to provide "organizational alignment, information availability, resource portfolio optimization, and resource complementarity". (Tamm et al., 2011) Griendling and Mavris show how resource portfolio optimization can be accomplished by using the large amount of information contained in DoDAF to create executable models such as Markov Chains and System Dynamic models and evaluate alternatives. (Griendling & Mavris, 2011)

McCaskill focuses on how DoDAF architecture primitives can be used for analysis at the CDD or CPD stage by amalgamating architectures to create enterprise level architectures for interoperability analysis. (McCaskill et al., 2007) There has also been work on how architecture can be used for capabilities-based acquisition decisions by using the architecture framework as a common language. (Dickerson et al., 2004) Dickerson et al. describe a methodology that applies DoDAF architectures to the systems engineering steps of requirements analysis, functional analysis, synthesis, and design verification. They demonstrate how one can describe and assess the interoperability and integration of a "family of systems" using architecture products.

However, the adoption of enterprise architectures, particularly DoDAF, has not been without its challenges. Although DoDAF is mandated for every acquisition program, it has not been adequately implemented into the systems engineering lifecycle process and is merely another deliverable. (Russell, 2005) There is also a lack of a searchable central repository and standard terminology that would be required for a thorough analysis. (McCaskill et al., 2007) The architecture products are housed in "document libraries, databases, [and] architecture artifacts owned by different communities," while the information exist in "varying levels of detail, formats, purposes, forms, and timeframes". (Martinez, 2014)

Russell poses key questions to ensure architectures are tied to the analysis and decision-making process and remain relevant. Particularly pertinent questions deal with determining what decisions need to be made and what information is needed to make those decisions. (Russell, 2005) Martinez discusses how the development of enterprise architectures driven by these decision support needs can augment the decision-making cycle and can yield more applicable results than a standard template of architectures. (Martinez, 2014)

This thesis investigates the information available through DoDAF at the early capability concept (ICD) stage. This is an initial excavation into what can be revealed about the capability portfolio through DoDAF. This thesis assumes that DoDAF's structured format will expose linkages between aspects of a capability faster than a free text document.

3. Understanding JCIDS

A description of the JCIDS enterprise is warranted before delving into DoDAF. An understanding of the enterprise and its interrelated parts will reveal the need for systems thinking in gaining a holistic understanding when validating a capability requirement. The following information springs from a research project conducted by the author and a team during an MIT course called "ESD.38: Systems Architecting Applied to Enterprises" taught by Dr. Donna Rhodes. Our understanding was gleaned from readings and interviews conducted with subject matter experts within the JCIDS enterprise. This section describes the enterprise landscape, stakeholders, process element, and knowledge element of the JCIDS enterprise to provide the context for how a validation for a capability requirement is conducted during the early ICD stage.

3.1 Enterprise Landscape

3.1.1 External Landscape

The JCIDS enterprise affects and is affected by external factors. As previous chapters alluded to, JCIDS sits within the DoD ecosystem that is influenced by geopolitical and regulatory factors. (Nightingale & Rhodes, 2015) This will be referred to as the external landscape.

The global threat environment that impacts military operations and strategy will in turn impact portfolio management considerations during the capability requirement assessments and review in JCIDS. Natural disasters, terrorist groups, and foreign conflicts are unpredictable threats in the environment that the Joint Capability Portfolio is designed to address and are necessary considerations during JCIDS analysis processes. The military ensures its capabilities are able to successfully operate in this threat environment and has the responsibility to fill any gaps with the required capabilities.

The political environment directly affects the civilian responsibility of acquisition which in turn influences the capabilities of the military. This ecosystem factor consists of major stakeholders such as Congress, the Office of Management and Budget, the Office of the Secretary of Defense, the Office of the Service Secretaries, and industry. (Fox, 2011) Differences in values and priorities of these parties have significant effects over the acquisition of the capability requirement. For example, Congress might support a particular program that industry or the executive branch may disagree with, which can prolong the process beyond planned completion times. (Fox, 2011) There are also instances where the division of responsibility disappears. This can happen when a civilian authority such as Congress begins to specify technical performance parameters as it did with the Small ICBM (Intercontinental Ballistic Missile). (Fox, 2011)

These players monitor and provide oversight as well. Hence, regulatory changes also wield considerable influence on the analysis and validation of capability requirements since regulations dictate how the JCIDS enterprise manages the Joint Capability Portfolio. For instance, the National Defense Authorization Acts are examples of policies that have expenditure implications on the acquisition system. (Schwartz, 2014) Also, the current fiscal environment bears heavily on the affordability analyses during the later stages of JCIDS and is a unique consideration for the enterprise architecture.

In addition to JCIDS, it is also important to note the other two components of the larger DoD acquisition enterprise depicted in Figure 2. The three components include:

1. The Joint Capabilities Integration and Development System (JCIDS)—for identifying requirements.
2. The Planning, Programming, Budgeting, and Execution System (PPBE)—for allocating resources and budgeting.
3. The Defense Acquisition System (DAS)—for developing and/or buying the item. (Schwartz 2014)

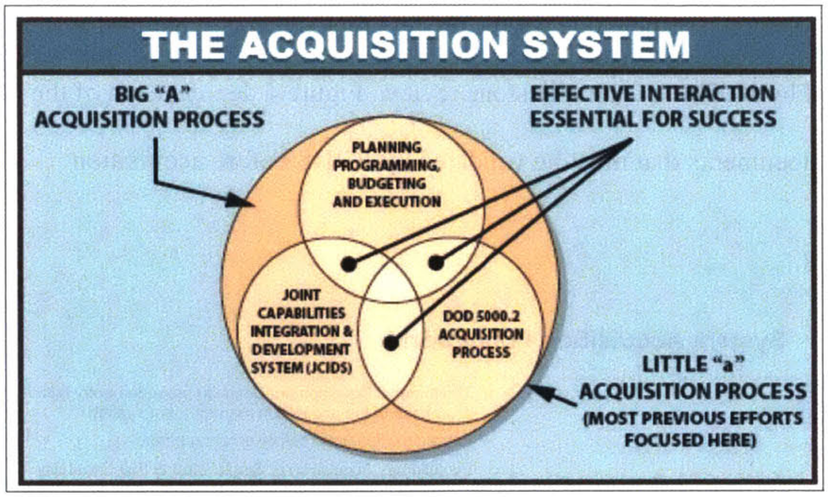

Figure 2: DoD Acquisition System. Source: (U.S. Government Accountability Office, 2014)

JCIDS interacts with the PPBE processes during the Program and Budget Review (PBR), the Chairman's Program Recommendation (CPR) and the Chairman's Program Assessment (CPA). See Figure 3. JCIDS provides the warfighters' capability needs and assessments as PPBE makes funding decisions for planning and programming.

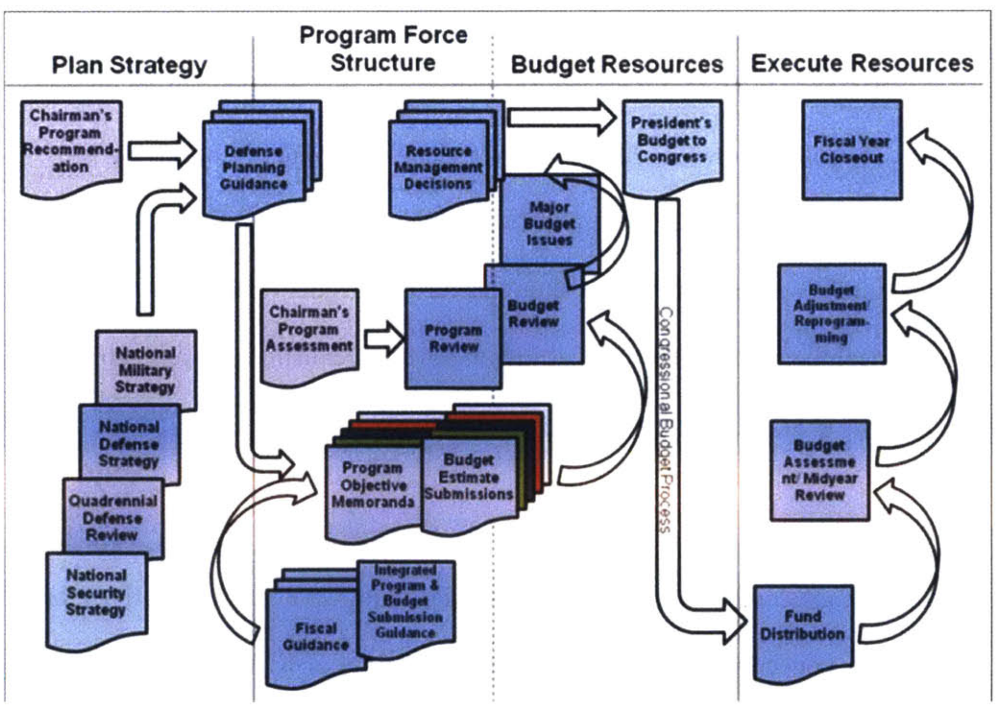

Figure 3: Overview of Resource Allocation and Interaction with PPBE. Source: (US Department of Defense, 2015)

The Defense Acquisition System is responsible for the process of acquiring a materiel system after the capability is validated by JCIDS at each milestone review. Figure 4 depicts each of the milestones and the capability documents that must be validated by JCIDS before acquisition activities commence.

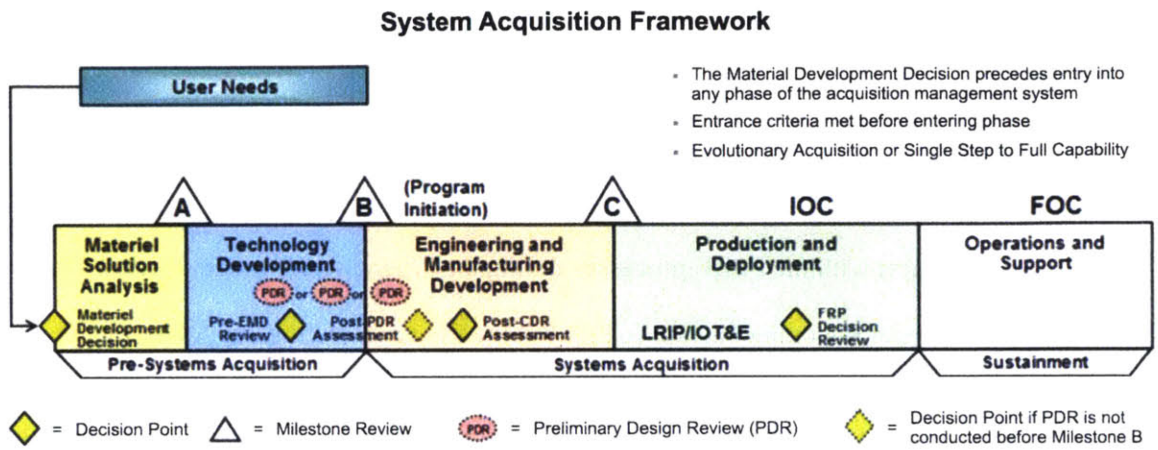

Figure 4: System Acquisition Framework. Source: ("System Acquisition Framework," n.d.)

Together, the three components take a desired capability from concept to deployment. (GAO, 2015) They are designed to mutually inform each other's processes to acquire non-materiel and materiel systems for the warfighter. However, there is a danger of operating in isolation with their interaction only happening at the Deputy Secretary level. (Augustine et al., 2009) This results in a linear process that doesn't simultaneously consider operational requirements, technological feasibility, and affordability to develop realistic and applicable capability solutions. (Davis et al., 2008)

3.1.2 Internal Landscape

The internal landscape can be described by enterprise values, strategic imperatives, or identity. This thesis mainly concentrates on the enterprise capabilities of JCIDS and how well DoDAF provides these capabilities. The capabilities are the emergent "system properties" of the enterprise that enable it to deliver value to the end user. (Nightingale & Rhodes, 2015) The following two vital capabilities were part of our ESD.38 research findings and are the focus of this thesis.

Visibility: This refers to the ability of the personnel within JCIDS to be able to view and to have access to knowledge about necessary elements of multiple capability requirements for analysis and validation. This is necessary to ensure interoperability across the DOTMLPF spectrum but is currently difficult to accomplish. Knowledge resides with the subject matter experts, in disparate architecture repositories, and in official publications/studies/capability documents in the Knowledge Management/Decision Support (KM/DS) system. This can result in redundant and disconnected capability solutions.

According to the recently published CJCSI 3170.01I the "KM/DS system is the authoritative system for processing, coordinating, tasking, and archiving capability requirement documents, validation memorandums, and related action items when classified at or below the level of SECRET." Currently, KM/DS is mainly a scheduling and filing tool that doesn't provide analysis or advanced search capabilities. Although it contains a repository of past capability documents and studies that would be useful for analysis, it can be difficult to conduct analyses by searching through existing related capabilities or ongoing capability documents.

Traceability: While visibility pertains to having access to the knowledge of multiple capability requirements and its associated information, traceability refers to JCIDS' ability to connect all of that information to perform a thorough analysis. The Capability Mission Lattice (CML) is an integrating construct developed by the Joint Staff that depicts the essential features of a capability requirement to enable that traceability. See Figure 29. It "incorporates existing JCIDS taxonomies, such as the JCAs, as well as extending into other pertinent areas of the requirements domain." (Ahmed, 2014) However, the ability to connect all of these elements is a manual time intensive process that may be incomplete due to lack of visibility.

These two internal capabilities are essential for capability planning and analysis and were found to be highly valued by all the stakeholders within JCIDS. This enables decision makers to validate a capability requirement with thorough knowledge. Without these two capabilities, the ICD-stage analysis will be incomplete and will result in faulty requirements for the following acquisition stages.

This section discussed external and internal landscape factors, which can change and create new capability gaps for the Joint portfolio to fill. These factors provide critical information for the validation of capability requirements as direct influencers in the analysis process.

3.2 Background of the Stakeholders

"Understand what stakeholders value and how that may change in the future" (Nightingale & Rhodes, 2015)

This section describes the composition and functions of each of the JCIDS stakeholders, which are grouped into four categories to capture their enterprise-level functions: Sponsors, Gatekeeper, Analysts, and Validation Leadership. See Figure 30 for a further decomposition of these groupings into a multitude of offices. Each stakeholder, particularly the sponsors, gatekeeper, and analysts, will require a thorough understanding of the capability requirement and the capability portfolio. Section 4 will explore how well DoDAF information can provide this holistic understanding at the ICD-stage.

3.2.1 Sponsors

Sponsors include the military services, combatant commands, and other DoD components that require materiel and non-materiel capabilities to accomplish their missions. The Sponsors support their capability requirements with studies and assessments which support their need for a particular prioritized capability. They must invariably have all the necessary information at their disposal to ensure that the proposed capability requirement meshes the needs of the joint force and the current capability portfolio.

3.2.2 Gatekeeper

The Joint Staff Gatekeeper of the JCIDS enterprise, formally designated as the J-8/Deputy Director of Requirements (DDR), serves as the entry point for the submission of all capability requirement documents (other than those with SAP/SAR designation) to the JCIDS process. The gatekeeper ensures that the submissions meet procedural requirements as outlined in the JCIDS manual. This office leads the comment process and the KM/DS staffing for the request.

The gatekeeper also identifies the lead and supporting FCBs for processing the capability requirement and determines the Joint Staffing Designation (JSD) for validation. This office, in coordination with J-8/JRAD, J-8/CAD, and J-8/PBAD, also assigns the relevant POCs for the FCB review and chairs the GO/FO integration meetings.

3.2.3 Analysts

This stakeholder group conducts the assessments and provides the recommendations that drive concept development, capabilities planning, capabilities integration, and force development. This is a tall order because it must have a thorough understanding of the Joint Capability Portfolio to assess capability requirement alternatives and minimize risk. (US Department of Defense, 2009)

The analysts are comprised of multiple FCB Working Groups that are staffed by the particular FCB chairs to provide analytical support pertaining to their capability area. For example, the J-6/C4CD (C4 Cyber Division) serves as the Working Group lead and Secretariat for the C4/Cyber FCB and supports all C4/Cyber related analyses.

Analysts also include assessment support organizations (J-8/JRAD, J-8/DDI, J-8/CAD, J-8/JFCD, J-8/PBAD) that provide special expertise that pertains to requirements. For example, the Joint Requirements Assessment Division (JRAD) contributes requirements expertise and assessment whereas the Capabilities and Acquisition Division (CAD) contributes acquisition expertise and assessment.

Other SMEs within the Joint Staff can be tasked to provide analysis for the FCB. RFIs can be submitted to SMEs external to the FCB such as the military services or Combatant Commands. (Wills, 2012)

3.2.4 Validation Leadership (FCB leadership and the JROC/JCB)

The FCB Chairs are six General/Flag Officers or civilian equivalents, who provide oversight over their respective capability areas. The Building Partnerships and Corporate Management JCAs are primarily handled outside the FCB by other Joint Staff organizations. The FCB Chairs ensure proper analyses are conducted on their capability requirements and provide recommendations to the JCB/JROC for validation. This occurs throughout their participation in the GO/FO Integration Groups where they ensure integration occurs across JCAs.

The validation authorities include the Joint Requirements Oversight Council (JROC), Joint Capability Board, and the J-8/DDR (for JUONs). The JROC is chaired by the Vice CJCS and is comprised of the Vice Chiefs/Assistant Commandant of the services. Combatant Command representatives also have a seat on the board especially when the capability requirement pertains to their geographic command. The JROC validates capability documents that may support Acquisition Category (ACAT) I/IA programs and provides a recommendation to the CJCS. The ACAT levels indicate the costs, the amount of reporting requirements, and the level of oversight. ACAT I programs are considered to be major defense acquisition programs that are more costly. ACAT II and III are the non-major programs. The JCB validates the documents that are associated with ACAT II and below programs. The JCB is chaired by the Director of J-8 and is comprised of General/Flag Officers or civilian equivalents from the military services, combatant commands, or DoD components.

For those programs that are both ACAT II and below and beneath the level of JCB interest, the Sponsors have independent validation authority after they receive the proper joint staff certifications and endorsements. These capability documents are referred to as Joint Integration documents. The capability documents that don't need Joint Staff certifications or endorsements are called Joint Information documents and can be validated at the Sponsor level. See Table 1 for the required certifications and endorsements by the joint staff.

Certifications and Endorsements	JROC or JCB Interest	Joint Integration	Joint Information
Threat Assessment / Intelligence Certification	Joint Staff	Joint Staff	Sponsor
Weapon Safety Endorsement	Joint Staff	Joint Staff	[redacted]
FP KPP Endorsement	Joint Staff	Sponsor	Sponsor
SS KPP Endorsement	Joint Staff	Sponsor	Sponsor
Sustainment KPP Endorsement	Joint Staff	Sponsor	Sponsor
NR KPP Certification	Joint Staff	Joint Staff	Sponsor
Energy KPP Endorsement	Joint Staff	Joint Staff	Sponsor
DOTmLPF-P Endorsement	Joint Staff	Sponsor	Sponsor

Table 1: Certification and Endorsement Responsibilities. Source: (US Department of Defense, 2015)

3.3 Capability Portfolio Management Processes

JCIDS Capability Portfolio Management processes center around identifying, prioritizing, and managing the capabilities of the joint force. This mainly supports the acquisition management system as depicted in Figure 5 but also assists other studies such as the Capability Gap Assessment (CGA) and Chairman's Portfolio Assessment (CPA), as mentioned in the previous section. This thesis mainly focuses on the information required during the processes during the Initial Capability Document (ICD) stage of the deliberate planning process. The following description of the process is applicable to the validation of all three capability documents: ICD, Capability Development Document (CDD), and Capability Production Document (CPD). Section 3.4.1 provides a more in-depth description of the ICD.

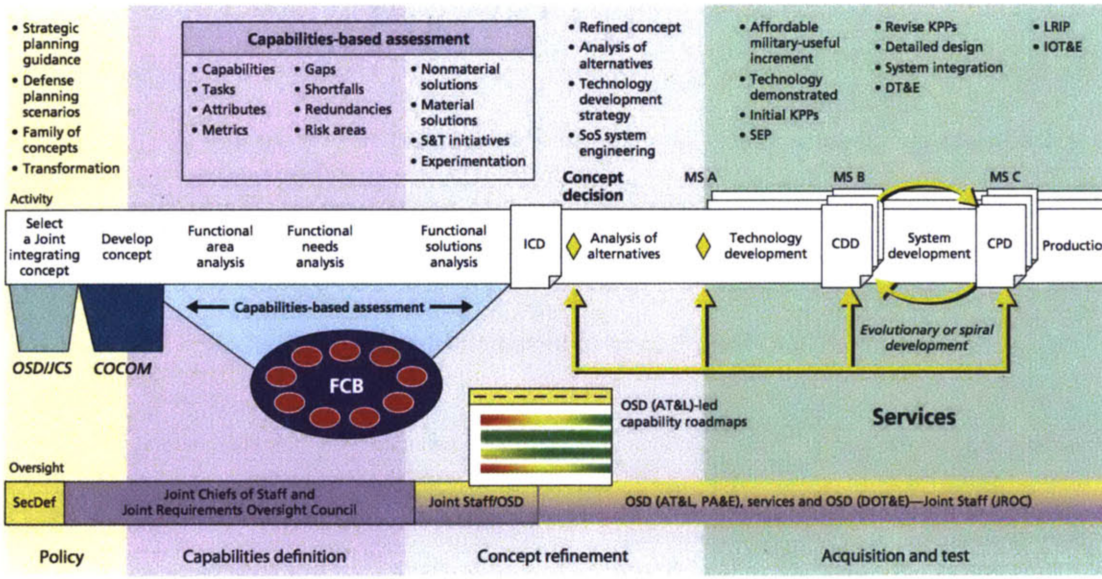

Figure 5: Acquisition Management System. Source: (Davis et al., 2008)

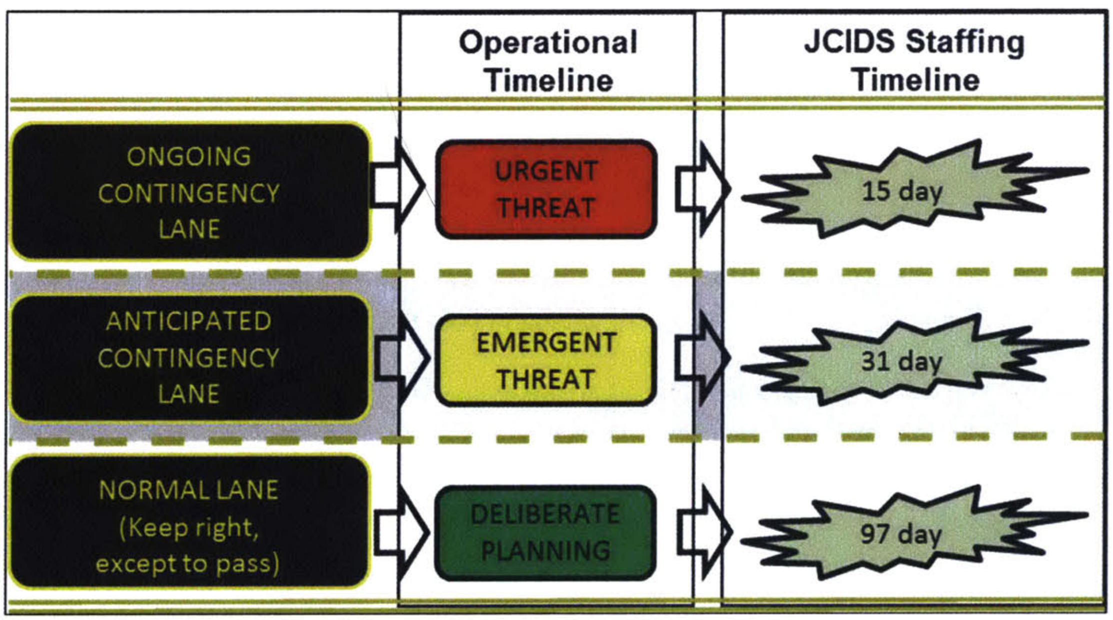

Figure 6. JCIDS Process Lanes. Source: (US Department of Defense, 2015)

The JCIDS deliberate planning process begins with a sponsor's submission of a capability requirement. A sponsor, such as a combatant command or an individual service, conducts their individual requirements generation process and creates a capability document to submit to JCIDS. The Sponsor Gatekeeper first loads the capability document and its supporting data into the KM/DS (US Department of Defense, 2015). In this pre-staffing phase, the Joint Staff

Gatekeeper reviews the submission for completeness in format, supporting studies, required information, and understandability. The Sponsor then corrects the document as necessary.

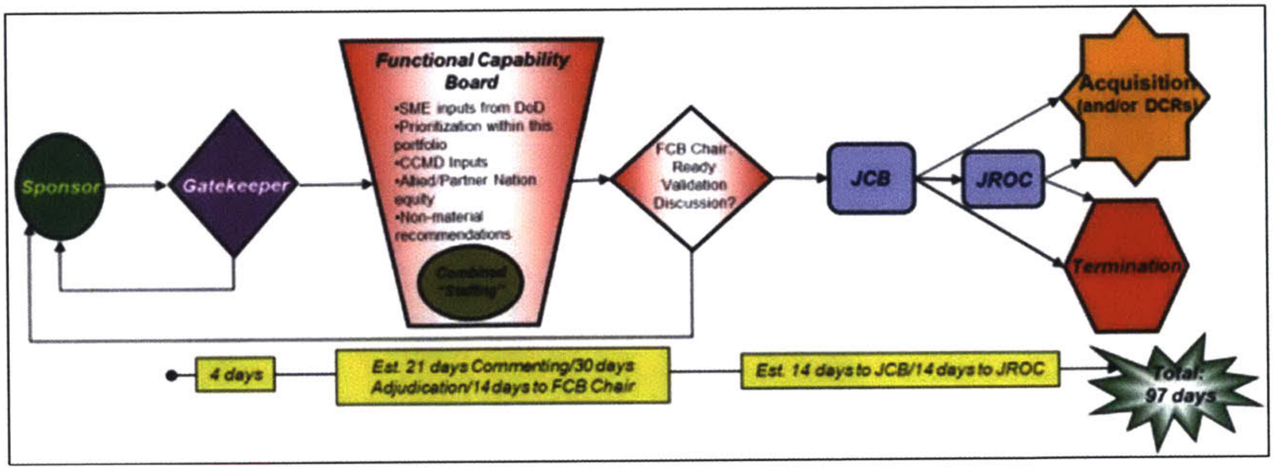

Figure 7. JCIDS Staffing Overview. Source: (US Department of Defense, 2015)

The Gatekeeper then identifies a lead Functional Capability Board (FCB) to conduct requirement and capability gap analysis. The FCB designation depends on the nature of the capability and its relation to one of the six capability areas. Figure 8 shows how the six FCBs are organized according to the currently established Joint Capability Areas (JCAs). If the capability requirement spans multiple capability areas, additional support FCBs may be assigned. The Gatekeeper also determines the level of JSD (Joint Staffing Designator) for validation to either the Joint Capability Board (JCB) or the JROC, depending on the Acquisition Category (ACAT) level.

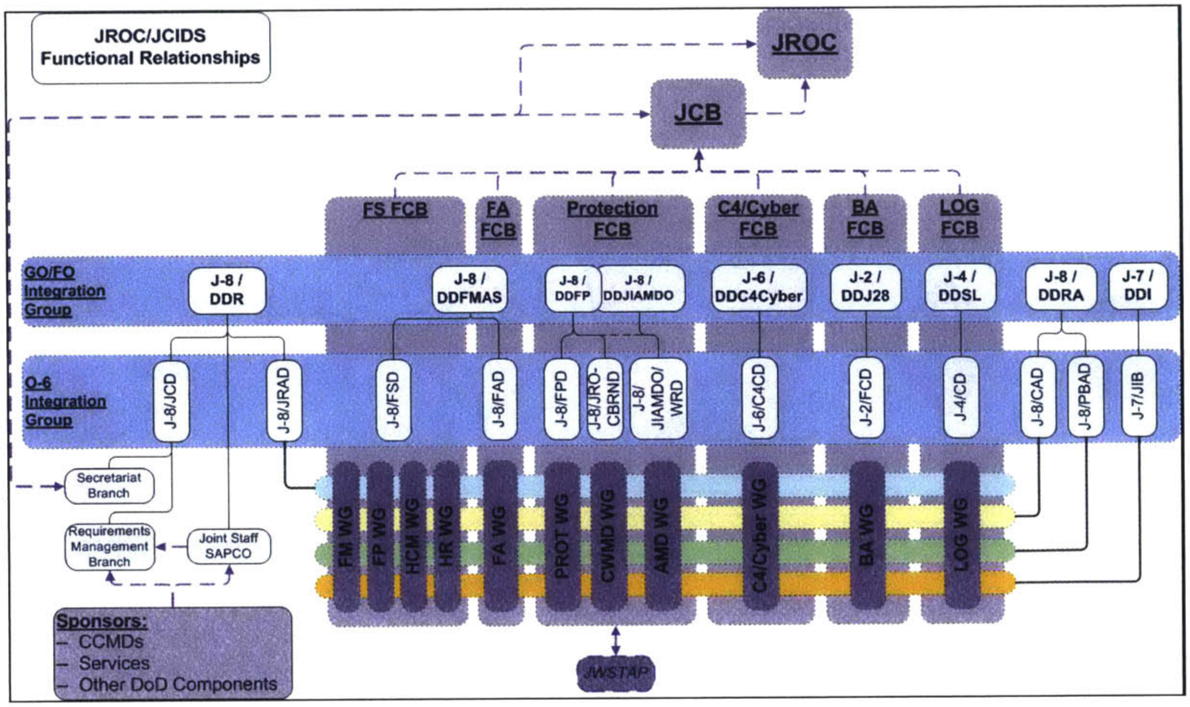

Figure 8. Hierarchical JCIDS Functional Architecture. Source: (US Department of Defense Joint Staff, 2015)

From the JCIDS manual (US Department of Defense, 2015), the Gatekeeper also coordinates with certifying and endorsing organizations for the document review. This, along with lead FCB assignment, initiates the staffing process of the JCIDS enterprise (p. E-13). The pre-staffing phase is four calendar days long (p. F-3) As sponsors are preparing their capability documents they are encouraged to dialogue with Joint Staff and endorsing/certifying organizations as necessary to avoid rework (p. F-4). (US Department of Defense, 2015)

Subject Matter Experts (SME) review their respective sections during the staffing phase. All of these section advisors are expected to conduct their review in light of a comprehensive understanding of the entire Joint capability portfolio (US Department of Defense, 2015). See Table 2 for which offices are responsible for particular sections of the ICD.

During the front-end analysis of the ICD-stage, stakeholders in the JCIDS enterprise are ensuring that the identified capability requirement is needed in the capability portfolio. This is a vital step since a validated capability requirement provides the conceptual underpinning for the rest of the acquisition phases. A validated ICD indicates that there is a recognized capability need and a capability solution can be further pursued. The use of systems thinking based on accurate information is essential at this stage to enhance the visibility and traceability of the joint capability portfolio. This will inform the stakeholders in the process of certifying that the capabilities are not unnecessarily redundant, is interoperable, and is a priority for the joint force.

Joint Staff Primary Equities	Other/Advisors	ICD Sections
J3/J5	CAPE (for ISCs)	Operational Context
J-2/IRCO	USD(I)	Threat Summary
FCBs, J-8/JRAD, J-8/CAD, J-8/PBAD	MDA, ASD(A), ASD(R&E), ASD(L&MR), USD(I), DOD CIO, DASD (T&E), DOT&E	Capability Requirements and Gaps/Overlaps
J-1, J-4, J-5, J-7, J-8/FD	USD(P), USD(P&R), ASD(L&MR)	Assessment of Non-Materiel Approaches
Validation Authority	MDA, CAPE	Final Recommendations

Table 2: Joint Staff Sections Responsible for ICD sections. Source: (US Department of Defense, 2015)

After final comments from the endorsing/certifying section, the Sponsor will adjudicate within 30 days. After adjudication and the FCB working groups review, the document is ready for validation unless the FCB Chair recommends a redo. There are 14 days allotted for this review process. The FCB Chair then recommends either a positive or negative validation to either the Joint Capability Board (JCB) or JROC (US Department of Defense, 2015). The JCB has 14 days and JROC has 28 days to validate.

3.4 Knowledge Elements – Initial Capabilities Document (ICD) and DoDAF

"We are drowning in information but starved for knowledge."(Naisbitt, 1983)

In order for this analysis to be successful, all stakeholders must have traceability and visibility of the information about the capabilities in the joint portfolio. This information will drive the stakeholders' decision-making calculus during the validation process. "Commanders make and implement decisions based on information. Information imparts structure and shape to military operations. It fuels understanding and fosters initiative." (Department of the Army

Headquarters, 2012) Although this is in reference to operations, the importance of information can certainly be applied to the JCIDS enterprise.

There are multiple representations of the information about a capability requirement. Capability documents and DODAF products, which outline the sponsors' requested requirements and drive the JCIDS process, are two such knowledge representations. These guide the decision-making during the development process of the capability. The capability requirement is validated in stage gate reviews at the end of which the JROC decides whether or not to recommend an investment on a materiel or non-materiel requirement. (Wirthlin, 2009)

3.4.1 Background on the Initial Capability Document (ICD)

There are three types of information documents generated by the sponsors that drive the capability requirement analysis process for validation: capability documents (materiel requirement), DOTmLPF-P Change Recommendation (DCR) (non-materiel requirement), and Joint Urgent Operational Need (JUON)/Joint Emergent Operational Need (JEON)/DoD Component Urgent Operational Need (UON) (contingency operation capability requirement). (US Department of Defense, 2015)

This section describes the contents of the Initial Capability Document (ICD) as outlined by the latest JCIDS manual to provide the reader a sense for what knowledge is represented in the capability document. This section also discusses Colonel Ahmed's work with creating an ontology and extracting information from the ICD of three capability requirements to discover interdependencies. (Ahmed, 2014)

The ICD is a capability document that describes the materiel capability requirement and justifies the need for the capability in the joint force. The ICD outlines one or more capability requirements that close or mitigate unacceptable capability gaps. A capability solution is not specified until the ICD is validated. It is important to note that JCIDS requires that DODAF products be aligned with information in the capability documents. Any changes must be reflected in both DODAF and capability documents. The ICD along with DODAF are supposed to contain enough information about a capability requirement required by the FCB to conduct analyses and provide a recommendation to JROC. Table 3 depicts the sections of the ICD and its description.

ICD Sections	Description
1. Operational Context	• Paints the picture of how the capability requirement of the ICD will contribute to joint operations and identifies measurable operational outcomes. The information in this narrative should match the DODAF Operational Viewpoints. • Traceability to missions / ROMO / scenarios / CONOPs / concepts / OPLANs / CONPLANs • Relevancy of a CBRN environment • **Timeframe** for IOC and FOC of the capability requirement • Required measurable operational outcomes • **Effects** required to achieve the operational outcomes • Contribution to the integrated joint/multinational warfighting force • **Other enabling capabilities** required to achieve the desired operational outcomes
2. Threat Summary	• Associated DIA and Service-approved threat products • Threat capabilities associated with the proposed capability requirement in the expected operational environment
3. Capability Requirements and Gaps/Overlaps	• Initial objective value of the capability requirement operational attributes necessary to achieve mission objectives with moderate operational risk • Assessment of operational implications of risk • Associated JCAs, task, conditions, standards from UJTs/Service tasks, ROMO, timeframe under consideration • Difference between the initial objective value and current or planned operational performance levels • Capability requirements that overlap with current or planned capabilities • The impact of the capability gap or overlap on the operational context
4. Assessment of Non-Materiel Approaches	• Non-materiel approaches to close or mitigate capability gap • Remaining capability gaps that require materiel solution • Capabilities of allied or partner nations/US government departments or agencies/DoD Components • Assessment of quantity changes of current capability solutions • Intelligence community interoperability and support requirements
5. Final Recommendations	• Non-materiel recommendations that are part of the materiel solution • Non-materiel recommendations independent of materiel solution • General materiel recommendations (new, replace, upgrade) • The impact of the gap or overlap on the operational context • Technologies with potential to mitigate capability gap • Acceptance of operational risk • Estimated resources required/available/unavailable

Table 3: ICD Content. Source: (US Department of Defense, 2015)

To examine how the information required in an ICD could aid decision makers, Colonel Ahmed explored notional ICDs for the F-35 and F-22. He created a basic ontology to organize the information about affordability and critical technologies about these two aircrafts. (Ahmed 2014)

Since the two aircraft have had issues with information exchange interoperability so he tested to see whether an ontology would have exposed those issues earlier in the process.

A brief description of an ontology is warranted. The quote at the beginning of this section alluded to the immense amount of information that is available to the stakeholders of JCIDS. There are numerous studies and documents that contain the necessary information. However, until the information is digestible and analyzable, the analysis process will be long, costly, and incomplete at best. An ontology can aid in this endeavor. It is useful for sharing and analyzing knowledge using a consistent vocabulary within a group. (Gruber, 1993) It provides more information than a database in that it describes the underlying relationships, properties and concepts that exist in a particular domain of that group. The common vocabulary also allows for reuse and clarity about assumptions.

Ontologies generally consist of classes, slots, and instances. Some ontologies use different terms but these are usually the simple elements. Classes describe the concepts. For example, a class could be "Ground Vehicles", which describes all ground vehicles. This can be divided into subclasses that are more specific like "tracked" and "wheeled". The slots, a description of the properties of the concepts, can be "armor level", "capacity", or "max speed". An instance is an actual value for each class and slot. A HWWMV is an instance of the "wheeled" subclass with a value of "low armor" in the "armor level" slot. The knowledge base grows as classes and slots are filled with more instances and values according to defined rules.

It is important to note that the correct ontology is the one that proves useful in a particular application. There will be a variety of ways to define a model in the domain but some will be more viable than others. Therefore, the ontology and the knowledge base are developed through an iterative process.

Colonel Ahmed used the Capability Mission Lattice (CML), created by the Joint Staff as the basis of a basic ontology. See Figure 29. The CML is an integrating construct to ensure traceability across operational activities and mission threads, strategic guidance, concept of joint operations, threats, Joint Capability Areas, and materiel/non-materiel capability solutions. (Ahmed, 2014) This construct depicts the major fields that are associated with capability requirements, which in turn helps assessments and identification.

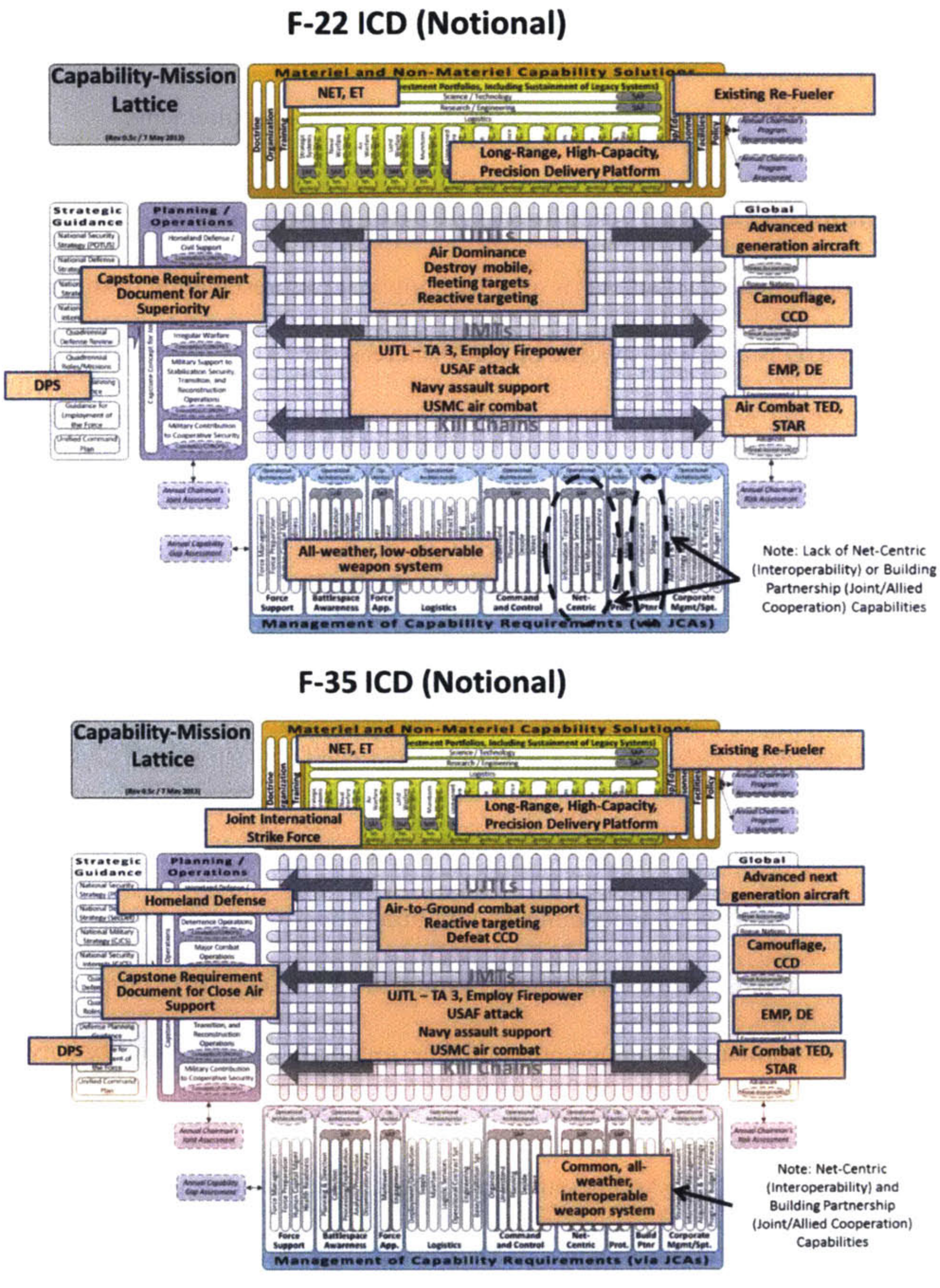

Figure 9: Basic Ontology of Notional F-22 ICD and Notional F-35 ICD. Source: (Ahmed, 2014)

The case study in Colonel Ahmed's thesis presented the challenge of how the United States Air Force F-35 and F-22 were going to communicate with each other. The two aircraft required disparate data systems while the F-22 was becoming increasingly reliant on the F-35. The process of architecting the two data link systems proved to be challenging and protracted. Colonel Ahmed demonstrated that even a basic ontology, based on the information required in an ICD, reveals a gap between the capability areas of Net-Centric and Building Partnerships. A more detailed and mature ontology might have helped the process by revealing disconnects earlier in the process. This could perhaps do the same for future capability requirements.

3.4.2 Background on the DoD Architecture Framework (DoDAF)

In addition to the ICD, DoDAF is another knowledge representation of the capability requirement. The ICD is a JCIDS-specific product whereas DoDAF is prevalent throughout the DoD. The Office of the Secretary of Defense (OSD) expects DoDAF to be a mandatory standard across the department for any major policies that deal with systems:

> *DoD Components are expected to conform to DoDAF to the maximum extent possible in development of architectures within the Department. Conformance ensures that reuse of information, architecture artifacts, models, and viewpoints can be shared with common understanding. Conformance is expected in both the classified and unclassified communities, and further guidance will be forthcoming on specific processes and procedures for the classified architecture development efforts in the Department.* (DoD Deputy CIO, n.d.-d)

The need for capturing DoD information in architectures predates DoDAF. DoDAF was originally titled the C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance) Architecture Framework 1.0. (Dam, 2015) It provided a standardized way of comparing architectures and determining the interoperability between DoD systems as they started to grow in complexity in the 1990s. The Architecture Working Group (AWG) who created the C4ISR Architecture Framework made further refinements as users proposed changes and corrections. (Dam, 2015) This led to the development of DoDAF in 2003, which became more data-centric and emphasized capabilities rather than requirements. The DoD Chief Information Officer (CIO), who is also the Assistant Secretary of Defense for Networks & Information Integration (ASD/NII), develops and maintains DoDAF. The latest update has been in 2012 with DoDAF 2.02, which gives the architect more freedom to tailor the viewpoints to meet their needs. (DoD Deputy CIO, n.d.-a) Figure 10 captures this evolution of the architecture framework.

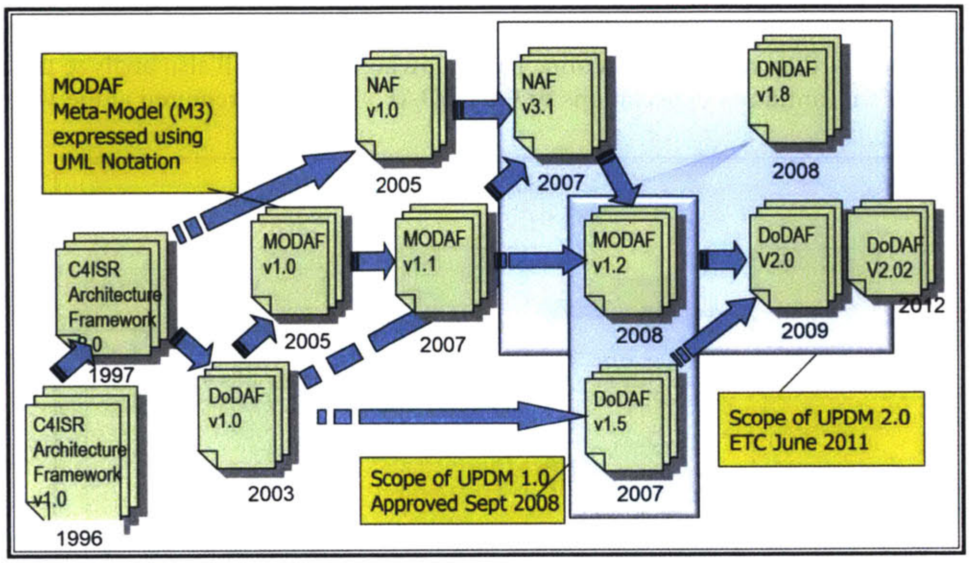

Figure 10: The Evolution of the Architecture Framework. Source: (Dam, 2015)

The Defense Information Systems Agency (DISA) enables search through various architecture repositories through Enterprise Content Search and Discovery (ECS&D). This is supposed to allow users to map elements across architectures to identify gaps, overlaps and interdependencies. As mentioned earlier, these repositories, however, have not enabled reuse of architectural information as well as it should for modeling and simulation or other analyses. (McCaskill et al., 2007)

At this point, it is important to clarify the terms used in DoDAF to avoid confusion in this thesis. The following definitions come from DoDAF 2.02:

- A model is a template for collecting data and can be in the form of spreadsheets, graphical representations, or any other format that is easily understood.
- Data is information about the architecture that can be "collected, organized, and stored" according to the data groups provided by the DoDAF Meta-Model (DM2). These data groups will also be referred to as architecture primitives.

- A model populated with data produces a view, which conveys the data in an understandable format. See Figure 11.

- A viewpoint is comprised of one or more views and represents a particular aspect of the overall architecture that supports decision-making and communicated complex information about the particular system. There are eight interconnected viewpoints and the descriptions of each are in Figure 12. The viewpoints required at the ICD stage are explained further in the next section. The following section will also analyze the JCIDS manual's information expectations of the DoDAF viewpoints required at the ICD stage.

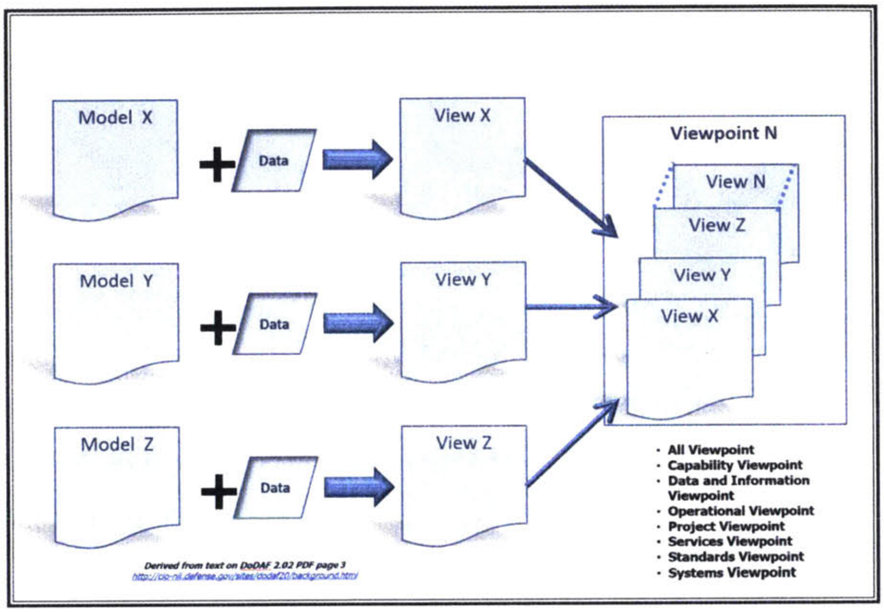

Figure 11: Depiction of Models, Data, Views, and Viewpoints. Source: (Dam, 2015)

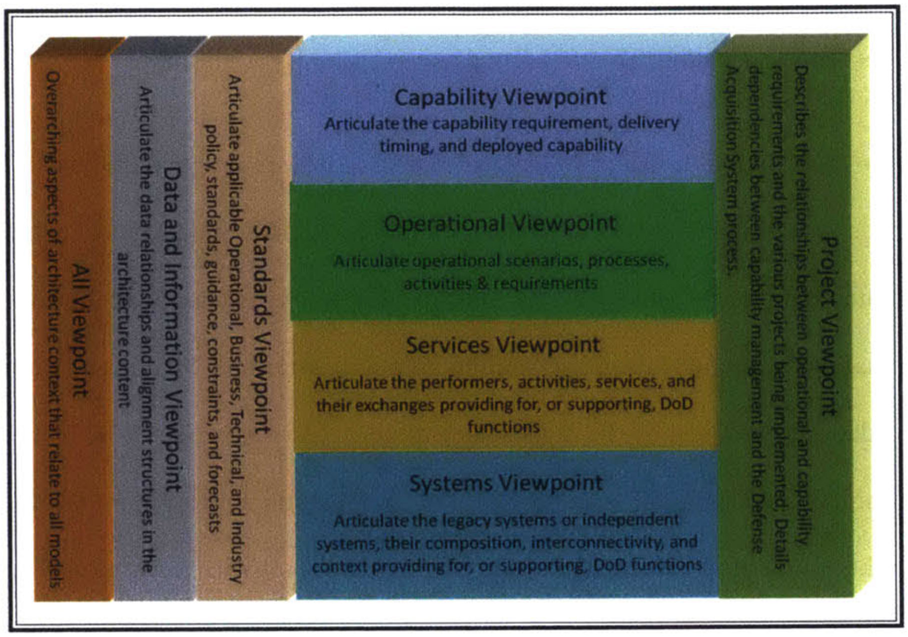

Figure 12: DoDAF Viewpoints. Source: (US Department of Defense, 2015)

DoDAF does not specify a methodology for architecture development nor does it provide a standard visualization template. Instead, the flexibility allows DoDAF to be used in all six core processes in the Department of Defense: JCIDS, DAS, Systems Engineering, PPBE, Portfolio Management, and Operations. The purposes of each process differ so DoDAF methodologies and visualization needs will also vary. This "fit for purpose" aspect of DODAF 2.0 can make comparisons challenging but puts the focus on keeping the architecture data-centric and tailorable to users' needs rather than restricting it to a particular template.

The J-6 Manual for the application of DoDAF to Warfighting Mission Areas (WMA) provides architecture guidance to add more structure and granularity to the overly flexible DoDAF for JCIDS processes. (Deputy Director Cyber and C4 Integration, 2015) This is intended to make DoDAF more workable for automated processes such as information sharing and architecture-based analysis across the DoD. (Deputy Director Cyber and C4 Integration, 2015) More specifically, this standard is applicable to the following Joint Staff and DoD activities:

- Joint Information Environment (JIE) governance
- Capability development, acquisition and analysis (e.g., JCIDS)

- Training, Modeling and Simulation
- Test and Evaluation
- Functional Capabilities Board analysis and review

The J-6 manual does not change DoDAF but standardizes certain data fields of DoDAF using DM2. The data in DoDAF is structured using DM2 (DoDAF Meta-Model), which replaces the Core Architecture Data Model (CADM). DM2 is an ontology extension of the concepts in IDEAS (International Defence Enterprise Architecture Specification), which is a "formal ontology foundation developed by the defense departments and ministries of the United States, United Kingdom, Canada, Australia, and Sweden in coordination with NATO". (DoD Deputy CIO, n.d.-e) This ontology provides a common language and promotes interoperability between systems across these countries. Figure 13 provides the DM2 core concepts and its level of applicability across DoD core processes.

DM2 CDM Core Concepts	Core Process Utilization						
	JCIDS Capability Mgmt	JCIDS Interop & Supp	DAS	PPBE	CPM	SE / SOSE	Ops Planning
Activity	●	⊙	◉	◉	◙	◉	◙
Agreement	⊙	◉	◉	⊠	⊠	◉	◉
Capability	●	◉	◯	◉	●	◉	◉
Condition	◯	⊙	○	⊙	⊙	⊙	◯
Data	◉	◯	⊙	○	◉	◉	⊙
DesiredEffect	●	○	◉	⊠	◯	⊙	●
Guidance	○	◉	◉	⊙	⊙	◉	◯
Information	◯	◯	⊙	○	◉	◉	◯
Location	⊙	⊙	○	⊙	⊙	○	◙
Materiel	◉	○	◉	⊙	⊙	◯	◯
Measure	●	◯	◯	⊙	◯	◉	⊙
MeasureType	●	◯	◯	⊙	◯	◉	⊙
Organization	⊙	○	○	⊙	⊙	○	◙
Performer	◯	◯	◯	◯	◯	◙	◯
PersonType	◉	⊙	⊙	○	⊙	⊙	◯
Project	⊠	⊠	◯	⊙	◉	⊙	◉
Resource	◉	◉	⊙	○	◉	◉	◯
Rule	⊙	◯	◉	○	⊙	◯	⊙
Service	⊙	◉	◉	⊙	◉	◙	⊠
Skill	◉	⊙	⊙	○	⊙	⊙	◯
Standard	⊙	●	◉	○	⊙	◯	⊙
System	⊙	◙	◙	◙	◙	●	◉
Vision	⊙	⊠	⊙	○	◉	⊠	○
ArchitecturalDescription	◯	◙	◉	⊙	◯	◙	◉

Legend

●	Critical role
◙	Substantial role
◯	Significant role
◉	Moderate role
⊙	Supporting role
○	Minor / optional role
blank	Insignificant / no role

Figure 13: DM2 CDM Core Concepts. Source: (DoD Deputy CIO, n.d.-c)

Information structured around the DM2 Core Concepts is supposed to allow a more structured approach and more rigorous analysis in analyzing a capability requirement than reading free text or going through an entire database because of the relationships across various properties and concepts are captured.

4. Assessing Available Information in DoDAF

Problems occur because the Department of Defense's weapon programs do not capture early on the requisite knowledge that is needed to efficiently and effectively manage program risks.
- Senate Committee Report 109-069 – S1042, Title VIII Acquisition Policy

DoDAF models will potentially allow a more structured approach to analysis by allowing stakeholders to quickly analyze data elements as opposed to unstructured text. Information structured as data elements will allow a more structured approach to analyzing a capability requirement or sharing information than reading free text or going through an entire database. In this sense, DoDAF is intended to save time and effort. Figure 15 indicates how structured information allows for more analytical methods than free text.

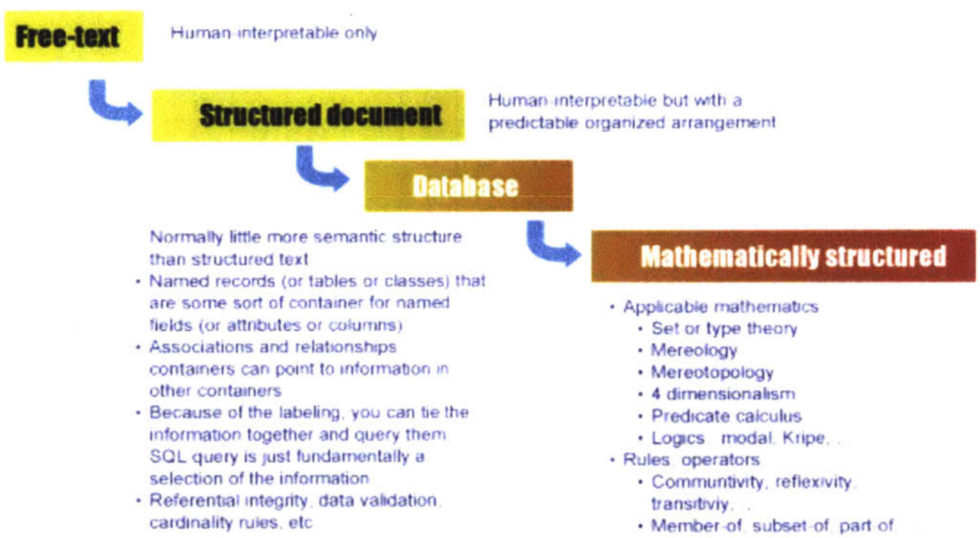

Figure 14: A Spectrum of Information Structuring. Source: (DoD Deputy CIO, n.d.-e)

Thus, the new JCIDS manual makes specific DoDAF viewpoints a requirement with each submission of an ICD. High quality DoDAF products and ICD would provide a description and vision of a capability requirement that is well aligned and traceable with the important information in the Capability Mission Lattice. These capabilities will develop system-level details as they are refined during the CPD and CDD stage but at the ICD stage the ICD and DoDAF should provide enough conceptual information to provide the decision-maker enough clarity to validate the capability.

Colonel Ahmed developed an early version of an ontology and demonstrated that the classes in the ontology did indeed identify critical interdependencies across three programs: Joint Future Theater Lift (JFTL), Joint Air-to-Ground Missile (JAGM), and Extended Range Unmanned Aerial System (ER UAS). (Ahmed, 2014) The ontology has since been refined and can potentially capture the information needed about a capability requirement to make validation decisions. This thesis builds upon his work and examines the amount of information DoDAF can provide for the decision-maker at the ICD stage.

This section examines to what extent this is true by determining the sufficiency and necessity of DoDAF in aiding the decision makers in the FCB. The author demonstrates what information is and is not able to capture, and what information is and is not needed in the FCB's analysis. This will ultimately reveal whether DoDAF can capture all the needed information about a capability requirement to enable analysts and decision makers to have a thorough understanding of the validity of a capability requirement through this knowledge representation, which is more amenable to data analysis.

This section begins with the information required by the decision-makers during the ICD stage. The following section uses notional capability requirements to demonstrate what information DoDAF and the ICD is able to capture and map it to the information required to validate the capability requirement.

4.1 Information requirements of the JCIDS Stakeholders

Intelligence is knowing a tomato is a fruit; understanding is not putting it in a fruit salad. (Ministry of Defence, 2010)

A common concern within the JCIDS enterprise is the inability to conduct a thorough analysis on a capability requirement. Decision makers in the JROC and FCB have asked the following questions to analysts within the JCIDS enterprise at the ICD stage:

- What other missions and functions would a solution for an identified gap address besides the need indicated by the organization seeking the validated requirement?

- How does the timeframe of the threat impact how to prioritize allocations in budget decisions?

- What other systems will be impacted negatively when adding a new capability? For example, a new capability on a tank might force alterations to the railcars that have to transport it cross-country to the port of embarkation. This would require identifying interconnections and dependencies of proposed systems (or legacy systems if it's too early to define a proposed solution).

- Can more units of another in-development, less capable system (or for that matter, a pre-existing, less capable system) be purchased to fill the capability gap as opposed to developing a brand new system? If so, roughly how much of that system would be needed?

These are difficult questions to answer without having full visibility and traceability of the joint capability portfolio. This indicates that the ability to compare capabilities across the portfolio is a key ingredient to having a clear understanding of a capability requirement and its impact. The JCIDS DoD Instruction outlines that stakeholders must have, "[k]nowledge of past requirements, acquisition, and budgetary decisions and rationale." (US Department of Defense J-8, 2015) Additionally, they must understand the "dependencies within and across capability requirement portfolios", "relationships between materiel and non-materiel capability solutions", and "potential changes to previous validation decisions to better close or mitigate capability gaps". (US Department of Defense J-8, 2015) They also must monitor "ongoing activities impacting their capability requirement portfolios, such as progress of AoAs and other acquisition activities, implementation of Joint DCRs, progress in satisfying JUONs, JEONs, and DoD Component UONs, etc." An analysis based on this understanding would lead to a validation.

The JCIDS manual defines a successful FCB analysis and validation process to be when all the stakeholders have a "clear understanding of how a new or modified capability requirement represents the best tradeoff in performance, cost, schedule, and quantity to minimize unnecessary redundancy and meet the needs of the Joint Force." As mentioned in the previous section, visibility and traceability are necessary for the stakeholder to accomplish this. A successful validation is the degree to which the stakeholder has this information and is able to know the capability requirements' impact on the capability requirement portfolio.

The implication is that the ICD and DoDAF viewpoints of each capability requirement contain enough information to provide the JCIDS stakeholders sufficient clarity to validate its need for further development of a solution. The ICD as a free-text document is flexible enough to capture this information in each of its five sections (Operational Context, Threat Summary, Capability Requirements and Gaps/Overlaps, Assessment of Non-Materiel Approaches, and Final Recommendations). Sponsors can be as detailed as they would like as they write the document. The DoDAF viewpoints, however, are more structured with certain allowable data fields. This is more restrictive but can potentially allow the JCIDS stakeholders to be more efficient in analyzing multiple capabilities by matching data fields rather than reading through documents. The seven DoDAF viewpoints (OV-1, OV-2, OV-4, OV-5a, CV-2, CV-3, CV-6) required with the ICD submission are supposed to mirror the "Operational Context" and Capability Requirements and Gaps/Overlaps" sections of the ICD. This already indicates that the information in the "Threat Summary", "Assessment of Non-Materiel Approaches", and "Final Recommendations" ICD sections could be absent from the DoDAF viewpoints. This section will verify this.

Certainly, there are additional studies to the ICD and DoDAF viewpoints that provide this information. The CBA, past analyses, and CGA can all inform the analysts and decision-makers on the pertinent information related to the operational environment and capability requirement. However, reading through all of these documents is inefficient and leaves room for error. DoDAF can potentially be a more structured way for the JCIDS stakeholders to access and understand this information.

4.2 DoDAF Viewpoints Required with the ICD Submission

DoDAF products other than the OV-1 were not always required with the ICD submission. The new 2015 JCIDS manual now makes it a requirement to include specific viewpoints with each submission of an ICD to augment capability requirement analysis. See Figure 15 for the required viewpoints. The JCIDS manual notes that a high level of detail of each of the viewpoints during the ICD-stage is not required. The information is still solution-neutral at the ICD stage. "Capability requirements should be general enough so as not to prejudice decisions in favor of a particular capability solution but specific enough to evaluate alternative approaches to achieve the capability." (US Department of Defense, 2015) These DoDAF products get updated and refined as the acquisition process progresses. Additionally, system level details are also added later during the Analysis of Alternatives (AoA) onto the Systems Viewpoints.

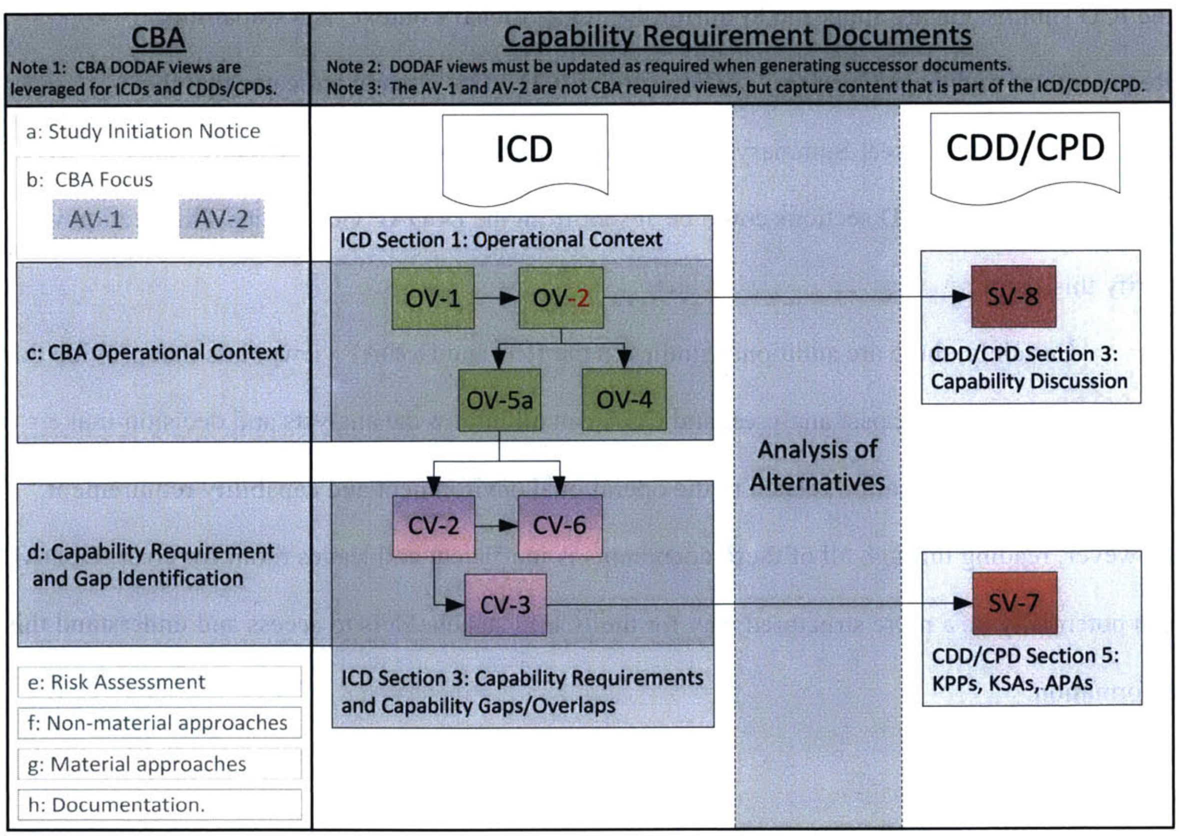

Figure 15: The Connection Between the CBA and Capability Requirement Documents. Source: (US Department of Defense, 2015)

The sponsor conducts a Capability Based Assessment (CBA) when there is a need for an assessment of a particular mission area. (US Department of Defense, 2015) The CBA captures all of the associated capability requirements and gaps that pertain to the mission area. Using this information, the sponsor then generates an ICD and its DoDAF viewpoints when the operational risk of an unmitigated capability gap is unacceptable. Figure 15 depicts the DoDAF viewpoints that correspond to the CBA steps and ICD sections.

This section describes each of the DoDAF viewpoints required at the ICD stage using a matrix (See Figure 31). The data elements of each of the viewpoints are presented. However, there many repeating and unnecessary data fields for this analysis. Figure 16 is an example of all the data fields available for an OV-5a. Figure 16 includes the required data fields annotated by "R", optional data fields annotated by "O", and required if applicable data fields annotated by "RA".

Model: OV-5a		
Data Fields	**Data Descriptions**	
Superior Operational Activity Identifier	The Identifier may capture the hierarchy structure of the OV-5a. The numbers may or may not be displayed on architecture itself	R
Superior Operational Activity Name Security Classification Markings	Security Classification of Parent Operational Activity Name	R
Superior Operational Activity Name	Verb-Noun name of the operational activity. May also include UJTs or Service Tasks. The Operational Activity name is established on the OV-5a	R
Operational Activity Identifier	Unique identifier for the operational activity. The Identifier may capture the hierarchy structure of the operational activities. In addition to the OV-5a, the Operational Activity Identifier may additionally be used in the CV-6, SV-5a, SV-5b, SvcV-5. In the OV-5b and OV-6c, it may be used as either the producing or consuming operational activity identifier.	R
Operational Activity Name Security Classification Markings	Security Classification of Operational Activity Name	R
Operational Activity Name	Work, not specific to a single organization, weapon system or individual that transforms inputs (Resources) into outputs (Resources) or changes their state. May also include UJTs or Service Tasks. The Operational Activity name is established on the OV-5a. The name can be replicated in the CV-6, SV- 5a, SV-5b, and SvcV-5. In the OV-5b and OV-6c, the data may be used as either the producing or consuming operational activity name.	R
Operational Activity Type Security Classification Markings	Security Classification of Operational Activity Type	R
Operational Activity Type	Object or DM2 type that describes the class of operational activity. If a Task, the Task list structure for the Operational Activity. Valid values are UJTL, AFUTL, AUTL, MCTL, NTTL.	R
Operational Activity Description Security Classification Markings	Security Classification of operational activity description	RA
Operational Activity Description	The operational activity description may be covered in the architecture AV-2. If it is not, an explanation of the location should be provided in this model.	O
Hierarchy Type Description Security Classification Markings	Security Classification of Hierarchy Type Description	RA
Hierarchy Type Description	An explanation of the type of hierarchy and relationship between the Superior-Subordinate (parent-children). Hierarchy type provides context to why the superior-subordinate grouping exists and does not relate to relationship type per se. The mereology of the structure is discussed here.	O
Ordinal	Numerical value that represents logical sequence for the elements to be displayed in. In most cases the identifier provides sufficient information. This may match the Identifier if it's provided	O
Fit For Purpose Element (Object) Name Security Classification Markings	Security Classification of Fit For Purpose Element (Object) Name	RA
Fit For Purpose Element (Object) Name	Fit For Purpose allows architects to enter various entities into their models and views that aren't germane to a DoDAF view, but are contextually required to meet the goals and mission that the architecture sets out to accomplish. This field provides the optional ability to capture those elements (objects). Include definitions for all Fit for Purpose elements in the AV-2	O
Fit For Purpose Element (Object) Type Security Classification Markings	Security Classification of Fit For Purpose Element (Object) Type	RA
Fit For Purpose Element (Object) Type	The DM2 type or Primitive type that the Fit For Purpose entity represents.	O
Relationship Type Identifier	The symbol or unique ID of the relationship type.	O

Figure 16: OV-5a Data fields. Source: (Deputy Director Cyber and C4 Integration, 2015)

For example, "Identifiers" and "Security Classification" data fields were excluded since they do not provide distinguishable pieces of information to the stakeholders. There are also data fields that are repeated in some viewpoints. For example, the author merged the "Operational Activity Name" and "Capability Name" data fields in CV-6 since it is their relationship that is valuable rather than their repeated information in isolation. In this case, a data field for the mapping relationship was created. The "Hierarchy Description" and "Relationship Type" data fields were also excluded since those same data fields appear in nearly every viewpoint. Although they provide useful information about the relationships between capabilities and operational activities, the author assumed information about these two data fields are inherent in the capabilities, organizations, operational activities data fields for analysis purposes.

There are also optional "Fit-for-purpose" data fields that allow the architect to include any relevant information about the capability requirement from a particular viewpoint. "Fit-for-purpose allows architects to enter various entities into their models and views that aren't germane to a DoDAF view, but are contextually required to meet the goals and mission that the architecture sets out to accomplish." (Deputy Director Cyber and C4 Integration, 2015) Although this allows for more information to be captured about capability requirement, capabilities across the portfolio can be difficult to compare since not every capability requirement will have the same fit-for-purpose data elements. This is essentially an unstructured data field and was also excluded.

4.2.1 The Operational Viewpoints at the ICD stage

The operational context in the CBA is described by the "timeframe under consideration, applicable threats, and relevant Service and joint concepts, CONOPS, objectives, and related effects to be achieved." (US Department of Defense, 2015) This is supposed to provide enough information for the OV-1, OV-2, OV-5a, and OV-4, which should correspond to the operational context of the ICD.

The OV-1 High Level Operational Concept Graphic provides a high level graphical description of what and how the capability requirement is supposed to accomplish the concept of operations. (US Department of Defense, 2015) A stakeholder can gain a general understanding of the capability requirement through this graphic. See Figure 17 for an example. A textual description usually accompanies the graphic. It is important to note that not all of the actual interconnections that exist in the CONOPS are depicted in the OV-1 graphic. Its purpose is not to provide a comprehensive picture of a concept but to provide a general understanding.

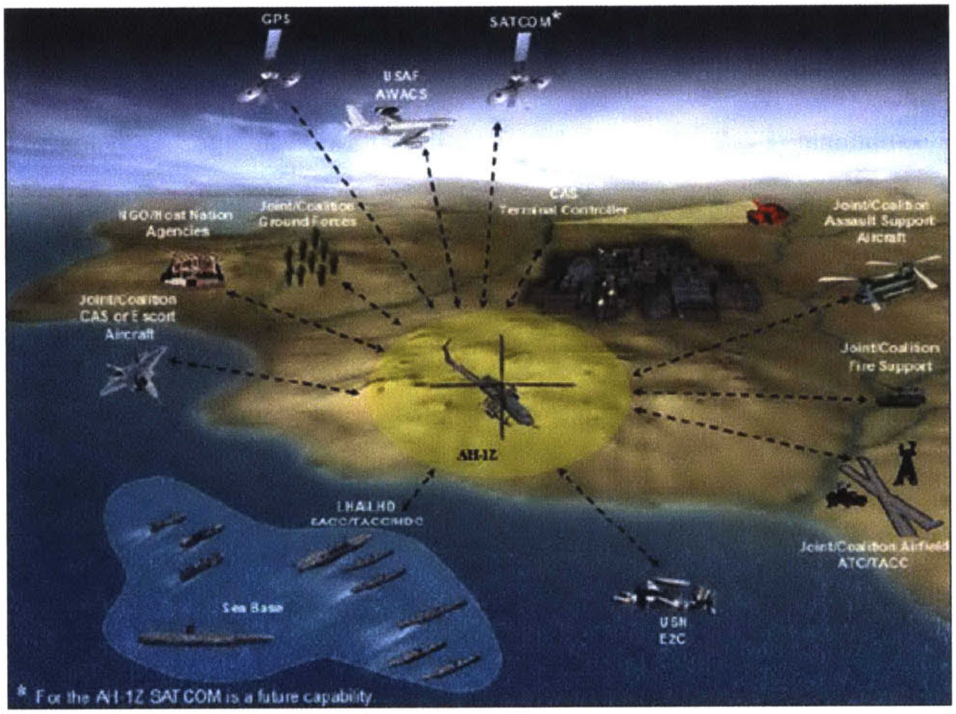

Figure 17: OV-1 Example. Source: ("2.8. Technology Development Strategy/Acquisition Strategy (TDS/AS) Outline," n.d.)

The OV-2 Operational Resource Flow Description goes into more detail and captures those interconnections. The OV-2 is intended to comprehensively provide the operational interactions in the operational context of the capability requirement. Thus, the OV-2 serves as a basis for the rest of the DoDAF viewpoints. The JCIDS manual indicates that the OV-2 is supposed to "translate the OV-1 picture into a complete set of nodes, activities, and interconnections upon which the rest of the architecture is based." (US Department of Defense, 2015) In so doing, other DoDAF viewpoints and content in ICD sections should be traceable to the "operational activities and effects applicable to the concepts and CONOPS" in the OV-2. (US Department of Defense, 2015)

The J-6 WMA standards provide further guidance into how the operational activities and effects are captured. It defines the interconnections as resources (information, funding, people, or materiel) exchanged between "performers, locations, organizations, activities, etc." (Deputy Director Cyber and C4 Integration, 2015) Table 4 contains the key data fields of an OV-2. It further defines performers as being “capable of responsibility” gives examples of “organizations, types of organizations and person roles.”

OV-2 Operational Resource Flow Description	Producing Performer Name
	Operational Resource Flow Name
	Consuming Performer Name
	Consuming Location
	Relationship Type
	Producing Location

Table 4: Key OV-2 Data Fields. Source: (Deputy Director Cyber and C4 Integration, 2015)

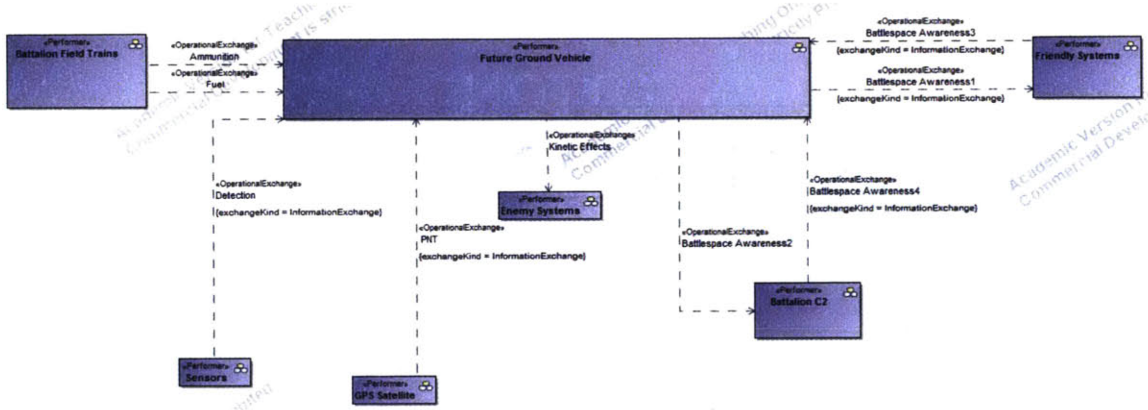

Figure 18: Graphical OV-2 of a Notional Ground Vehicle

However, there is no standardized practice for capturing operational activities or operational effects. For example, the previous OV-1 graphic includes nodes such as the US Navy E2C Hawkeye, SATCOM, and GPS systems. The GPS capability can be inputted as a performer that delivers situational awareness, which can be considered as a resource. This can be represented in an OV-2 by linking a performer ID to a “Communications” JCA 6.1 capability in CV-2 and the resource can be linked to an ID for “Communicate Operational Information” UJTL OP 5.1.1 in OV-5a. This would be able to describe an operational activity present in a concept. Unfortunately, there are no mandated data fields to connect these JCAs or UJTs to those that may be present in the CV-2, OV-5a, or other capability requirement architectures. This hinders the traceability across the viewpoints in the portfolio that the JCIDS manual expects.

Similarly, there is no standard practice for capturing operational effects in an OV-2. A CV-1 contains a data field for desired effects but this is not required at the ICD stage nor is there a standard way of linking it to the OV-2. "Operational effects" is also a semantically ambiguous term, which is discussed in more detail in Section 4.4.4. Determining what other capabilities might deliver similar operational effects would be a difficult query.

The OV-4 Organizational Relationships Chart identifies the organizations that are involved in the concept of operations. The organizations in this viewpoint may also be depicted in the OV-2 as performers. (Deputy Director Cyber and C4 Integration, 2015) Table 5 are the data fields in an OV-4.

OV-4 Organizational Relationship Chart	Superior Organization Name
	Organization Name/ Subordinate Organization Name
	Organization Location
	Relationship Type
	Hierarchy Type Description

Table 5: Key OV-4 Data Fields. Source: (Deputy Director Cyber and C4 Integration, 2015)

The OV-4 can depict not only hierarchical relationships as shown in Figure 19 but it also captures "relationships such as Administrative Control (ADCON), Operational Control (OPCON) and Tactical Control (TACON)." (Deputy Director Cyber and C4 Integration, 2015) Figure 19 is a graphical example of an OV-4 for an Armored Brigade Combat Team that would be involved with a notional ground vehicle capability.

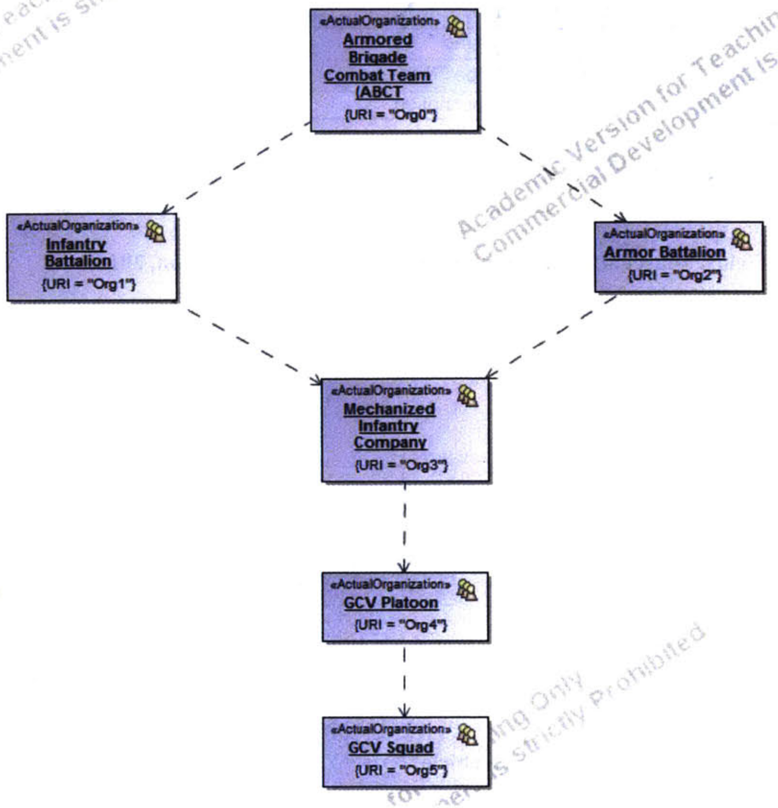

Figure 19: Graphical Depiction of an OV-4 for a Notional Ground Vehicle

The OV-5a Operational Activity Decomposition Tree relates the operational activities from the operational context described in the OV-1 and OV-2 to Universal Joint Tasks (UJT) or Service Tasks. This viewpoint is normally created after the OV-1. These tasks are expected to be traceable to the contents of other DoDAF viewpoints and the capability documents. Table 6 highlights the key data fields in an OV-5a and Figure 20 is a graphical representation of an OV-5a for a notional ground vehicle.

A challenging aspect of this viewpoint is the absence of a specified UJT or service task data field to link operational activity names to doctrinal tasks. The "Operational Activity Name" data field can contain this information but it is not standard practice. If there was a specified data field for tasks then it would be possible to search for other capability requirements that may be involve the same task. This search is unfortunately more difficult without a standard data field for tasks.

OV-5a Operational Activitiy Decomposition Tree	Superior Operational Activity Name
	Operational Activity Name
	Operational Activity Type
	Operational Activity Description
	Hierarchy Type Description
	Relationship Type
	Ordinal

Table 6: Key OV-5a Data Fields. Source: (Deputy Director Cyber and C4 Integration, 2015)

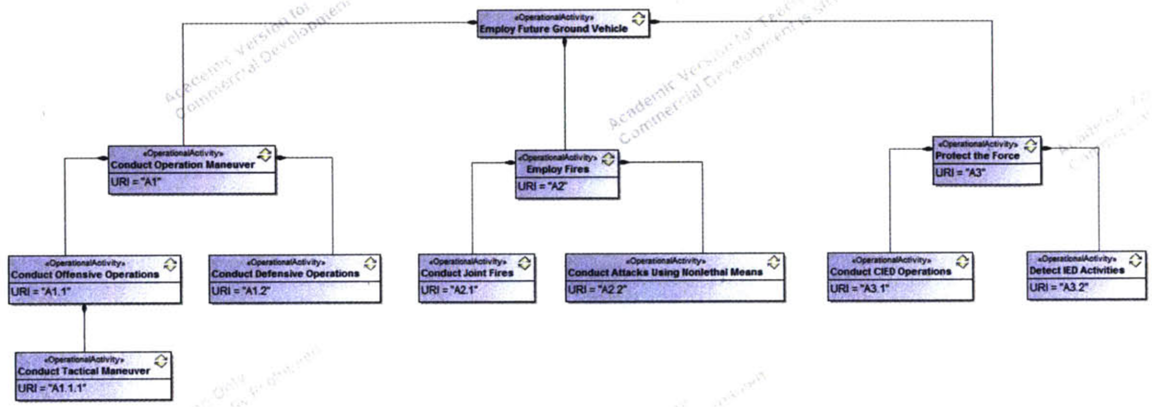

Figure 20: Graphical OV-5a for a Notional Ground Vehicle

4.2.2 The Capability Viewpoints at the ICD stage

The capability viewpoints (CV) are new additions to DoDAF 2.0. (DoD Deputy CIO, n.d.-f) They describe the capabilities that are related to the operational activities required in the concept of operations. The three capability views CV-2, CV-3, and CV-6 should correspond to the narrative of the capability requirement and gap section.

The CV-2 Capability Taxonomy provides a breakdown of the capabilities associated with the capability requirement outlined in the ICD. It can be presented in a tabular format like in Table 7 or in graphical format like in Figure 21 using commercial tools. The JCIDS manual specifies that the capability must correspond to Joint Capability Areas and be described with operational attributes and a quantitative criterion for operational effectiveness. These are the initial objective values of the capability requirement, which are used as a reference for the development of KPPs, KSAs, and APAs in the Capability Development Document. Appendix A to Enclosure C of the JCIDS manual provides examples of operational attributes such as accuracy, and interoperability, survivability.

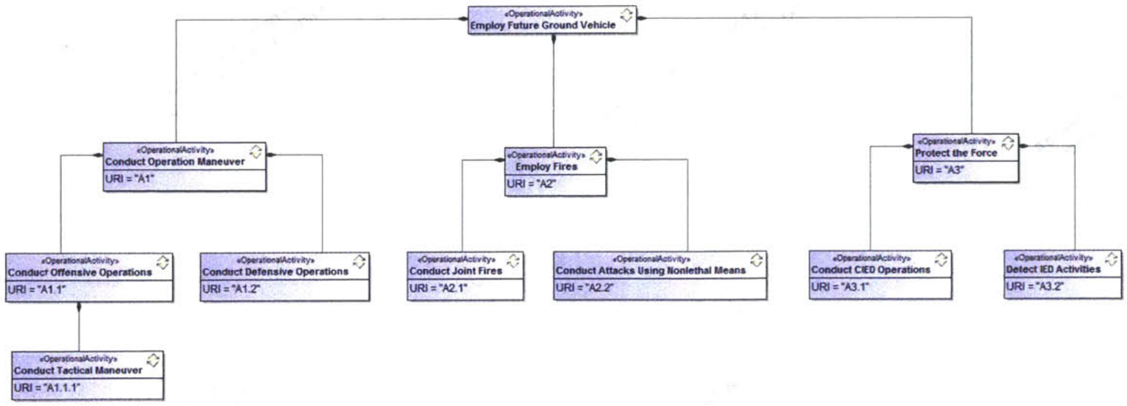

Figure 21: Graphical CV-2 for a Notional Ground Vehicle

CV-2 Capability Taxonomy	Capability / Capability Requirement Name
	Capability Type
	Capability Version Number
	Capability Description
	Capability Measure
	Capability Measure Type
	Hierarchy Type Description
	Relationship Type
	Capability Release Date

Table 7: Key CV-2 Data Fields. Source: (Deputy Director Cyber and C4 Integration, 2015)

Table 7 depicts the key pieces of information included in a CV-2. The highlighted fields are required while the other fields are either optional or required if applicable for the capability requirement. The operational attributes are captured in the "Capability Measure" and "Capability Measure Type" data fields. As mentioned earlier, the capability must be associated with a JCA. However, there is no distinct field for JCAs. J-6 WMA Standards allow the "Capability Name" data field to include JCAs or a customized name. An architect would have to create another "JCA" data field to link a custom name to a JCA. DoDAF is flexible enough to include this information to fully describe a capability requirement. However, the lack of a standardized JCA data field may create difficulties when conducting analyses on capabilities in the joint portfolio.

The CV-3 Capability Phasing depicts the timeframe of when specific aspects of the capability are required. It portrays the "incremental development strategy" if subsets of the capability are needed earlier than others. Key pieces of information of this viewpoint are depicted in the table below.

CV-3 Capability Phasing	Capability Name
	Phase Name
	Phase Start Date
	Phase End Date
	Relationship Type
	Superior Capability Name
	Capability Time Start Date
	Capability Time End Date
	Organization Name
	Phase Description

Table 8: Key CV-3 Data Fields. Source: (Deputy Director Cyber and C4 Integration, 2015)

The "Capability Name" data field is established in CV-2 and it is linked to the phase start and end dates. The 'Capability Time Start and End Date" data fields can be used when multiple capabilities occur at different times in a phase.

The CV-6 Capability to Operational Activity Mapping provides the stakeholder the traceability between CV-2 information and OV-5a to ensure interconnectedness. This is the only connection to the operational viewpoints out of the three capability viewpoints. Commercial tools can keep inventory of the data elements of a particular capability requirement so that they can be reused for multiple viewpoints. For example, the JCAs and UJTs used for CV-2 and OV-5a, respectively, are automatically added to a CV-6 matrix to depict their relationships. See Figure 22.

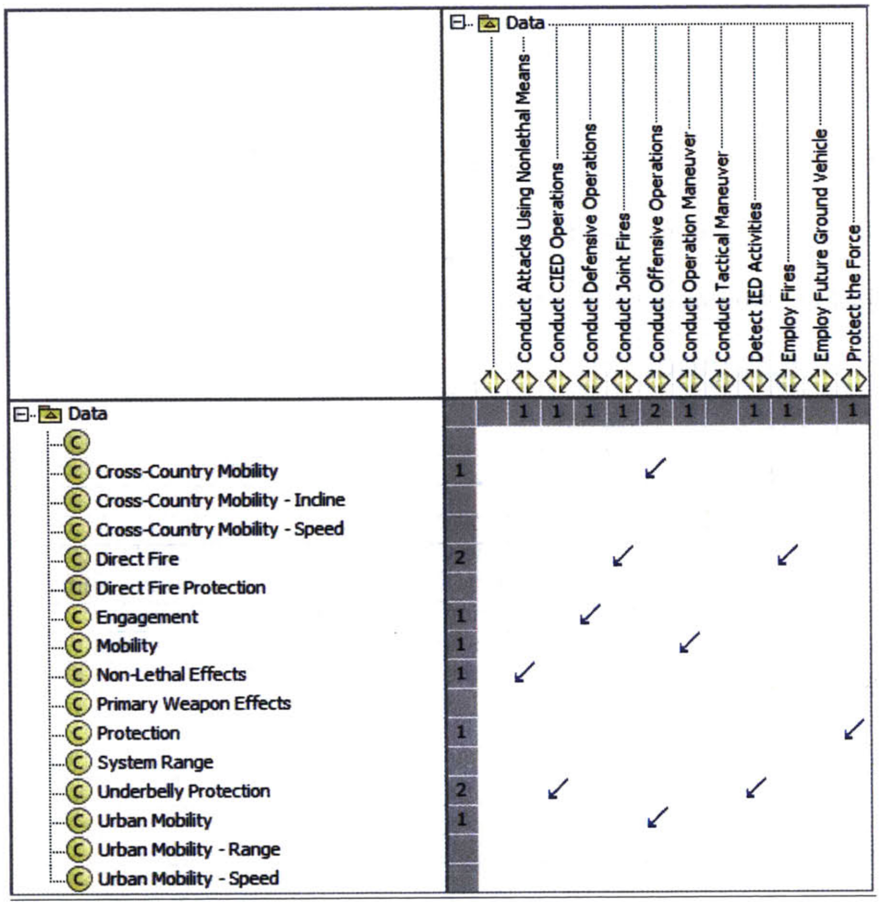

Figure 22: Matrix CV-6 for a Notional Ground Vehicle

4.2.3 Summary

This section provided an overview of the operational and capability viewpoints required at the ICD stage of the JCIDS process. It also examined the structure of the viewpoints and potential challenges that may arise because of its flexible nature. Again, the overall objective of this thesis is to examine how well DoDAF can provide information for the JCIDS stakeholders. This is under the assumption that a structured architecture framework like DoDAF will provide the stakeholders a more holistic understanding of the capability portfolio by allowing faster queries and more visibility into the traceable elements. This would aid in making informed recommendations and decisions about whether to proceed at the ICD stage.

The main challenge was the lack of standardized data fields and guidance for capturing JCAs and tasks. The permissive nature of DoDAF viewpoints allows an architect to capture unrestricted amount of information at varying levels of specificity. However, this flexibility detracts from the availability of information during later queries or analyses. Table 9 depicts the findings in this section. The next two sections will use the ICD content to further gauge the amount of information DoDAF can capture.

Viewpoint	Challenge	Implication
OV-2	No specified data field to annotate applicable JCAs and UJTs or service tasks	More difficult to quickly query across multiple OV-2s, OV-5as, or CV-2s to examine related capabilities with the same operational activities or JCA. This also hinders traceability across capabilities within the portfolio.
OV-5a	No specified data field for UJTs or service tasks	
CV-2	No specified data field for JCAs	

Table 9: Section 4.2 Summary

4.3 Alignment between the ICD and DoDAF

The matrix in Figure 31 captures the alignment between the ICD and DoDAF and depicts the information that is available without any additional human intuition or sources. The mandatory and optional data elements for each DoDAF viewpoint are derived from the J-6 WMA architecture standards and the ICD content information is from the JCIDS manual. The ICD sections represent the information needs of a stakeholder while the DoDAF data fields represent the readily available information since it can be more easily queried than a repository of ICDs. This section examines the information that are aligned between the two.

Before examining the actual data elements, a brief description of the matrix is warranted. The left column depicts the information elements that are required in each ICD section as mandated by the JCIDS manual. The other three ICD sections, in addition to the "Operational Context" and "Capability Requirements and Gaps/Overlap" sections, are included in the matrix to see how the information is aligned. There can be much variability in adherence to these standards simply due to the flexibility of a free-text document like the ICD. However, the JCIDS manual gives us a baseline to the mandatory information that the Gatekeeper will be looking for with each capability requirement submission.

The top row contains the mandatory and optional data fields in each DoDAF viewpoint required at the ICD stage. There are 147 total data fields in these seven viewpoints. Table 10 provides the break down of the number of data fields for each viewpoint.

DoDAF Viewpoint	Number of data fields
OV-1	16
OV-2	22
OV-4	17
OV-5a	20
CV-2	22
CV-3	25
CV-6	25
TOTAL	147

Table 10: The Number of Data Fields in Each Viewpoint. Source: (Deputy Director Cyber and C4 Integration, 2015)

As discussed in Section 4.2, the analysis for this thesis removed the redundant data fields such as “Identifiers” and “Security Classifications”. After excluding these data fields, there are 43 total data fields in the seven viewpoints that were used in the matrix.

The x’s in the matrix depict the alignment between the required information in the ICD with the required data fields in the DoDAF viewpoints. For example, the timeframe for IOC and FOC of the capability requirement in the “Operational Context” section of the ICD is fully captured by the CV-3 data fields of “Phase Start Date” and “Phase End Date”. There are only 5 pieces of information in the ICD that are well aligned with the required data fields of DoDAF. The timeframe of the capability, contributions to the joint warfighting force, associated JCAs, and associated UJTs are required information in both the ICD and DoDAF viewpoints. This alignment can be found in the matrix in Figure 32 in Appendix F: DoDAF-ICD Matrix (Aligned Information).

DoDAF Viewpoints		OV-5a Operational Activity Decomposition Tree							CV-2 Capability Taxonomy									CV-3 Capability Phasing										CV-6 Capability to task Mapping	
ICD Sections	DoDAF Elements / ICD Elements	Superior Operational Activity Name	Operational Activity Name	Operational Activity Type	Operational Activity Description	Hierarchy Type Description	Relationship Type	Ordinal	Capability / Capability Requirement Name	Capability Type	Capability Version Number	Capability Description	Capability Measure	Capability Measure Type	Hierarchy Type Description	Relationship Type	Capability Release Date	Capability Name	Phase Name	Phase Start Date	Phase End Date	Relationship Type	Superior Capability Name	Capability Time Start Date	Capability Time End Date	Organization Name	Phase Description	Operational Activity Mapped to Capability	Relationship Type
		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
Capability Requirements and Gaps/Overlaps	Associated JCAs								x	x	x	x																x	o
	Associated UJTs and service tasks	x	x	x	o	o																						x	o
	Associated timeframe																		x	x	x								

Figure 23: Aligned Information Between the ICD and DoDAF

Figure 23 is a snapshot of a portion of the matrix in Figure 32 that shows the ICD elements that are well aligned with the DoDAF elements. Information about the associated JCAs of the capability requirement in the ICD can be captured in DoDAF by the "Capability/Capability Requirement Name" data field in the CV-2. The three other data fields in the CV-2 provide further detail about the capability. The associated UJTs and service tasks are similarly captured by the three required data fields in the OV-5a.

4.3.1 Available Information in DoDAF

Solely based on the mandatory data fields (noted by the x's in the matrix), a stakeholder can determine the following about a capability requirement from the viewpoints:

- Phases of when the capability is expected to be completed (CV-3)
- Details about the resource flow (people, materiel, information) between performers (OV-2)
- Details about the organizational relationship that involves the capability (OV-4)
- Details about operational activities (UJTs and service tasks) (OV-5a)
- Relationships between the capabilities (JCAs) in addition to their measures (CV-2)
- Relationships between capabilities and operational activities (CV-6)

Details about resource flows, UJTs, organizational relationships, and JCA and UJT relationships are information elements that are usually not contained in the ICD. These are also details that are better presented in a structured format like DoDAF, which is more easily analyzable than a written document. For example, DoDAF allows one to systematically present the resources flows between performers in the operational context of the capability requirement. (Figure 18) This would be inefficient and more complicated to analyze if this information was in written form in an ICD.

This information provided by DoDAF can be leveraged to provide the stakeholders an understanding of the mission being addressed. For example, the OV-2 captures how information, people, and materiel flow between consuming and producing performers in an operation, which is not depicted in detail in an ICD. This provides information about what other systems and organizations will be involved by the capability requirement. In the case of the notional ground vehicle capability, a key consideration would be to ensure interoperability between the vehicle capability, sensors, and GPS satellites as information flows between all three. See Figure 18. Additionally, the OV-5a, CV-2, and CV-6 provide the associated Universal Joint Tasks and Joint Capability Areas in a structured format that portrays information about the capability requirement that does not exist in the ICD.

However, the seven viewpoints paint an incomplete picture of the capability requirement at the ICD stage. They particularly fall short in providing stakeholders insight into how a capability requirement relates to other capabilities in the portfolio. This is mainly due to optional and missing data fields that may not exist in every submission (blind spots in the capability portfolio), unclear terminology, and the absence of a standardized way of capturing additional information such as threat and enabling capabilities. The following section further examines the limitations.

4.4 Limitations of DoDAF

As mentioned earlier in Section 4.1, there is an expectation of JCIDS stakeholders to have an extensive knowledge of the capability portfolio. They should:

- have "[k]nowledge of past requirements, acquisition, and budgetary decisions and rationale" (US Department of Defense J-8, 2015)

- understand the "dependencies within and across capability requirement portfolios", "relationships between materiel and non-materiel capability solutions", and "potential changes to previous validation decisions to better close or mitigate capability gaps". (US Department of Defense J-8, 2015)
- monitor "ongoing activities impacting their capability requirement portfolios, such as progress of AoAs and other acquisition activities, implementation of Joint DCRs, progress in satisfying JUONs, JEONs, and DoD Component UONs, etc."

There is also an expectation that DoDAF will be able to meet some of these challenges by providing the ability to reuse "information, architecture artifacts, models, and viewpoints [that] can be shared with common understanding." (DoD Deputy CIO, n.d.-d)

There are indeed gaps between the DoDAF capabilities and the expected need for understanding the portfolio. From the outset, we know the viewpoints and ICD sections do not align as Figure 15 may suggest. The information elements of the operational context and capability requirements of the ICD sections do not cleanly correspond to specific DoDAF viewpoints. While the "Operational Context" and "Capability Requirements & Gaps/Overlaps" narrative of the ICD should be derived from the Operational and Capability Viewpoints of DoDAF, respectively, the matrix depicts how the two information sources actually tell different parts of the story. (Figure 31)

For example, the timeframe of the capability requirement in the "Operational Context" section is found in the CV-3 and not in the data fields of the Operational Viewpoints. Table 11 is adapted from the matrix and depicts the different versions of the operational context as told by the ICD and DoDAF viewpoints. This is also true for some information in the "Capability Requirements and Gaps/Overlaps" section that will appear in the Operational Viewpoints. For example, the associated UJTs of the capability requirement are captured in the OV-5a and not in a Capability Viewpoint.

ICD (Operational Context section)	DoDAF (OV-1, OV-2, OV-4, OV-5a)
Traceability to **missions / ROMO / scenarios / CONOPs / concepts / OPLANs / CONPLANs**	Graphic and textual **description of the concept** of the performers and operations involved with the capability requirement
Relevancy of a CBRN environment	The information/funding/people/materiel that flows between people/activities/organizations/systems **(operational resource flows)**
Timeframe for IOC and FOC of the capability requirement	The command structure or relationships among **organizations** that are affected by the capability requirement
Required **measurable operational outcomes**	Relevant **Universal Joint Tasks** performed with the capability requirement
Effects required to achieve the operational outcomes	
Contribution to the **integrated joint/multinational warfighting force**	
Other enabling capabilities required to achieve the desired operational outcomes	

Table 11: Operational Context Described by the ICD and DoDAF

The previous section demonstrated to what extent DoDAF can provide the expected understanding of the capabilities portfolio for the JCIDS stakeholders. The next section dives into where DoDAF may fall short.

4.4.1 Misalignment between the ICD and DoDAF Viewpoints at the ICD-stage

DoDAF is supposed to promote a "common understanding" across the DoD. (DoD Deputy CIO, n.d.-d) It should follow that the new DoDAF requirement at the ICD stage is able to fully describe the capability requirement as described in the ICD sections. However, there are misalignments in the availability of information so the stakeholders in JCIDS should have an understanding of the limitations of each information source. This section dives deeper into the missing information in DoDAF, which could limit the potential to increase visibility and traceability of the joint capability portfolio for JCIDS stakeholders.

The o's in the matrix are instances where the information in the ICD sections are contained in optional or in unstructured DoDAF data fields. Although this information can be captured in the viewpoints, its availability to the stakeholder is not guaranteed and may not be as easily analyzable. Figure 24 captures the portion of the matrix that shows the ICD elements that may be captured in optional or unstructured data fields. There are 2 pieces of information in the ICD that optional DoDAF data fields will be able to capture. Traceability to missions/concepts/operations/scenarios and conditions have optional data fields in DoDAF viewpoints at the ICD stage.

DoDAF Viewpoints		OV-1 High-level Operational Concept Graphic				CV-2 Capability Taxonomy								
ICD Elements	DoDAF Elements	Image Name	Image (Text) Description	Alternate Text	Relationship Type	Capability / Capability Requirement Name	Capability Type	Capability Version Number	Capability Description	Capability Measure	Capability Measure Type	Hierarchy Type Description	Relationship Type	Capability Release Date
ICD Sections		1	2	3	4	23	24	25	26	27	28	29	30	31
Operational Context	Traceability to **missions/operations/scenarios/concepts**		o	o										
	Relevancy of a CBRN environment								o					
Capability Requirements and Gaps/Overlaps	**Associated conditions**								o					
	Associated ROMO		o	o										

Figure 24: Matrix of Optional or Unstructured Information

For example, the relevant *range of military operations/scenarios/concepts/operations* and the *conditions* of the operational attributes that should be described in both ICD sections are not available in a structured way in any of the viewpoints required during the ICD submission. There is no mandatory data field for the associated conditions of the capability requirement as described in the "Capability Requirements and Gaps/Overlaps" section. Instead, they are optional additions in the "Image Description" and "Capability Description" in the OV-1 and CV-2 respectively.

These are non-compulsory data fields that obstruct the availability of this information during analysis.

The Joint Conditions follow a physical, military, and civil environment framework and is applicable for describing the operational context affecting or being affected by the employment of a capability. (US Department of Defense Joint Staff, 2011) The need for operational mobility of an amphibious vehicle during sea state 3 conditions may be a key feature of the capability gap. Alternatively, the capability could be required in conditions such "C1.1.3.5 Low Route Availability" and this would provide the stakeholder a basis for analyzing other existing capabilities used under such conditions. This can be captured in the "Capability Description" data field in the CV-2 that provides optional space for a text description of the "conditions under which tasks are performed". However, this is not required or structured information in the DoDAF viewpoints at the ICD stage.

An analysis based on conditions would be difficult for the stakeholder since this data field is essentially free-text and the inclusion of information about the conditions is optional. Should a decision maker ask what other capabilities are applicable to sea state 3 conditions, DoDAF would be inadequate. This is the same case for relevant missions, operations, scenarios, and concepts. There is an "Image Description" data field in the OV-1 that provides space to include this information, but this also unstructured. This information can also be formally captured in the data fields of OV-3 under "Mission/Scenario/UJTL/METL" and "Measure Condition" but are not required in the current set of viewpoints.

The m's and the ICD sections shaded in darker orange in the matrix depict the information that can be captured by creating multiple viewpoints. See Figure 25. For example, there is no specific viewpoint designated for threat capabilities that are described in the "Threat Summary" section of the ICD. One way to circumvent this problem is to create another set of viewpoints for depicting the threat capability.

DoDAF Viewpoints		OV-1 High-level Operational Concept Graphic		OV-2 Operational Resource Flow Description			OV-4 Organizational Relationship Chart					OV-5a Operational Activity Decomposition Tree			CV-2 Capability Taxonomy									CV-3 Capability Phasing			
DoDAF Elements / ICD Elements		Image Name	Image (Text) Description	Producing Performer Name	Operational Resource Flow Name	Consuming Performer Name	Superior Organization Name	Organization Name/ Subordinate Organization Name	Organization Location	Relationship Type	Hierarchy Type Description	Superior Operational Activity Name	Operational Activity Name	Operational Activity Type	Capability / Capability Requirement Name	Capability Type	Capability Version Number	Capability Description	Capability Measure	Capability Measure Type	Hierarchy Type Description	Relationship Type	Capability Release Date	Capability Name	Phase Name	Phase Start Date	Phase End Date
ICD Sections		1	2	5	6	7	11	12	13	14	15	16	17	18	23	24	25	26	27	28	29	30	31	32	33	34	35
Threat Summary	Threat capabilities in the expected operational environment	x	x	o	o	o	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
Assessment of Non-Materiel Approaches	Non-materiel approaches to close or mitigate capability gap						m	m	m	m	m				m	m	m	m	m	m	m	m	m				
	Capabilities of partner nations/US gov. agencies/DoD Comp.						m	m	m	m	m				m	m	m	m	m	m	m	m	m				
	Intelligence community interoperability and assessment						m	m	m	m	m				m	m	m	m	m	m	m	m	m				
Final Recommendations	Non-materiel recommendations that are part of the materiel solution						m	m	m	m	m				m	m	m	m	m	m	m	m	m				
	Non-materiel recommendations independent of materiel solution						m	m	m	m	m				m	m	m	m	m	m	m	m	m				

Figure 25: Matrix of Information that Require Multiple Viewpoints

For example, the lethal capability of an adversary is significant because our notional ground capability requirement will need to provide overmatch. This threat capability can be captured in an additional CV-2 and the organizational units of the adversary employing these capabilities can be captured in an additional OV-4. These threat capability viewpoints can then be linked in an OV-2 by denoting the kinetic effects created and consumed by a threat capability or its organization. This would reveal linkages between the various categories of capabilities as portrayed in Figure 26. However, there is no guidance for standardizing this practice and making this information available across the capability portfolio.

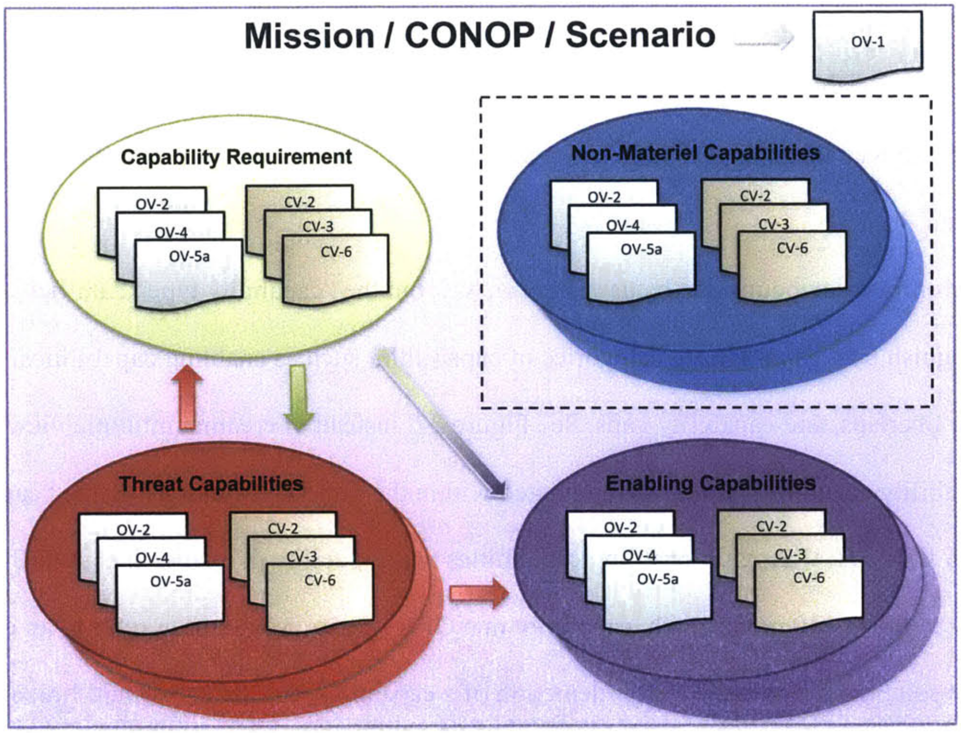

Figure 26: Possible Links Between Different Categories of Capabilities When Using Multiple Viewpoints

There is a "capability type" data field in CV-2 to identify whether it is a JCA or another custom category. However, there is no standard way or lexicon of capability types to distinguish between an enabling capability, a capability gap/overlap, non-materiel recommendations and the actual capability requirement. These are key pieces of information for the stakeholders in JCIDS.

For instance, a capability gap for a notional ground vehicle could be providing force protection of the mechanized movement of an infantry squad with a higher probability of protection from an Explosively Formed Penetrator (EFP). An enabling capability could be a non-materiel recommendation of refined training on how to detect EFPs during tactical movement.

Given this capability requirement, a JCIDS stakeholder would want to know what other existing or planned capabilities provide that probability of protection. There could also be other capability gaps that the training addresses. Visibility of these connections across the capability portfolio would provide a stakeholder a holistic understanding of how the capability requirement affects the portfolio. Perhaps a stakeholder with substantial experience in the JCIDS enterprise would have accumulated enough knowledge to understand these connections. However, anyone else would not be able to ascertain this information from the DoDAF viewpoints. He or she would have to read through past and current capability documents and studies to unearth this information.

Multiple viewpoints can be used here as well but the "capability type" data field in CV-2 can distinguish between different categories of capabilities such as enabling capabilities, capability overlaps, and capability gaps. See Figure 27. Instead of creating multiple viewpoints, these capability categories can be differentiated within the same viewpoint using the "capability type" data field in CV-2. Also, enabling capabilities and capability overlaps, like an airlift capability in the C-130 or net-ready capability in a GPS system, would often refer to an existing capability solution or system. A fuller depiction of a capability requirement would link existing DoDAF for these systems to the CV-2. However, this practice is also not standardized. The guidance for CV-2 captures the operational attributes and measures of the capability requirement but it does explicitly state to link or capture the associated attribute levels of the current or planned capabilities.

	DoDAF Viewpoints	OV-1 High-level Operational Concept Graphic		OV-2 Operational Resource Flow Description			OV-5a Operational Activity Decomposition Tree			CV-2 Capability Taxonomy									CV-3 Capability Phasing			
	DoDAF Elements / ICD Elements	Image Name	Image (Text) Description	Producing Performer Name	Operational Resource Flow Name	Consuming Performer Name	Superior Operational Activity Name	Operational Activity Name	Operational Activity Type	Capability / Capability Requirement Name	Capability Type	Capability Version Number	Capability Description	Capability Measure	Capability Measure Type	Hierarchy Type Description	Relationship Type	Capability Release Date	Capability Name	Phase Name	Phase Start Date	Phase End Date
ICD Sections		1	2	5	6	7	16	17	18	23	24	25	26	27	28	29	30	31	32	33	34	35
Operational Context	**Other enabling capabilities** required	x	x	o	o	o	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
Capability Requirements and Gaps/Overlaps	**Gap** operational performance levels									m	m	m	m	m	m	m	m	m				
	Overlap with current or planned capabilities									m	m	m	m	m	m	m	m	m				
Assessment of Non-Materiel Approaches	Remaining capability gaps that require materiel solution									m	m	m	m	m	m	m	m	m				

Figure 27: Matrix of Information that Require Multiple Viewpoints or Additional Guidance

There are a total of 8 pieces of information that DoDAF is flexible enough to capture but not through a standard method. These are fully depicted in the matrix in Figure 33. More rules for implementing DoDAF for capability requirements would decrease the flexibility. However, the tradeoff is information availability. All capability requirement submissions at the ICD stage may not have these architectures deeply developed, which limits the visibility of the entire capability portfolio.

The matrix also depicts untraceable information in the DoDAF viewpoints. There are ten pieces of information (rows highlighted in red) that appear in the ICD but not in the DoDAF viewpoints. This portion of the matrix is in Figure 34. For example, there are no data fields in the current set of viewpoints that capture the *measured desired effects* of the employment of the capability requirement. Assured mobility across a wide range of terrain (i.e. Urban, Desert, Jungle, Mountain) is an example of an operational effect not captured by the DoDAF viewpoints at the ICD stage. This information would be available in the CV-1 but it is not a requirement at this stage of the acquisition process. This lack of information could hinder the efficiency of the analyst or decision-maker since they will have to reference and search through the ICDs or other products to do simple comparisons or other types of analysis.

4.4.2 Misalignment between DoDAF and the CML

The Capability Mission Lattice (CML) can also reveal how DoDAF is aligned with the concepts that are used for capability requirement and gap identification. The CML is a framing construct that highlights important concepts such as strategic guidance, threats, and operations that are aligned with a capability. The matrix including the CML shows how traceability to strategic guidance and Resource/Investment information is not possible with this subset of DoDAF viewpoints. Strategic guidance refers to sources such as the National Security Strategy, Quadrennial Defense Review, and Unified Command Plan that provide higher-level vision for the Department of Defense. (See the CML for the complete list) These documents are certainly mutable but can be useful for providing strategic context for the capability requirement. It can also be useful to determine all the capability requirements that were generated for a particular source of strategic guidance. However, there is no structured data field that is specifically allocated for this information in the ICD DoDAF viewpoints. The "Vision Statement" data field in the CV-1 can include references to specific strategic documents but again, this is unstructured and not required at the ICD-stage.

DoDAF Viewpoints	OV-1 High-level Operational Concept Graphic				OV-2 Operational Resource Flow Description					
DoDAF Elements / ICD Elements	Image Name	Image (Text) Description	Alternate Text	Relationship Type	Producing Performer Name	Operational Resource Flow Name	Consuming Performer Name	Consuming Location	Relationship Type	Producing Location
ICD Sections: Capability Mission Lattice	1	2	3	4	5	6	7	8	9	10
Strategic Guidance										
Threats										
Conditions										
Missions/Planning/Operations			o	o						
Force Elements										
Resources/Investment										
Capability Solutions (Materiel/Non-Materiel)										
Capability Requirements										
Universal Joint Tasks (UJTs)										

DoDAF Viewpoints	OV-4 Organizational Relationship Chart					OV-5a Operational Activity Decomposition Tree						
DoDAF Elements / ICD Elements	Superior Organization Name	Organization Name/ Subordinate Organization Name	Organization Location	Relationship Type	Hierarchy Type Description	Superior Operational Activity Name	Operational Activity Name	Operational Activity Type	Operational Activity Description	Hierarchy Type Description	Relationship Type	Ordinal
ICD Sections: Capability Mission Lattice	11	12	13	14	15	16	17	18	19	20	21	22
Strategic Guidance												
Threats	m	m	m	m	m							
Conditions												
Missions/Planning/Operations												
Force Elements	x	x										
Resources/Investment												
Capability Solutions (Materiel/Non-Materiel)												
Capability Requirements												
Universal Joint Tasks (UJTs)							x					

DoDAF Viewpoints	CV-2 Capability Taxonomy								
DoDAF Elements / ICD Elements	Capability / Capability Requirement Name	Capability Type	Capability Version Number	Capability Description	Capability Measure	Capability Measure Type	Hierarchy Type Description	Relationship Type	Capability Release Date
ICD Sections: Capability Mission Lattice	23	24	25	26	27	28	29	30	31
Strategic Guidance									
Threats	m	m	m	m	m	m	m	m	m
Conditions				o					
Missions/Planning/Operations									
Force Elements									
Resources/Investment									
Capability Solutions (Materiel/Non-Materiel)	m	m	m	m	m	m	m	m	m
Capability Requirements	x			x					
Universal Joint Tasks (UJTs)									

Figure 28: Information Alignment between the CML and DoDAF

The absence of a resource/investment information data field in this set of DoDAF viewpoints is understandable considering that the capability requirement at this stage is solution neutral and should not reference a specific system. An estimated cost could be useful to the stakeholders by providing a general understanding of the resources required. This information can be obtained in the ICD but is not available in the DoDAF viewpoints. There is a "Total Lifecycle Cost" data field in the Project Portfolio Relationships Viewpoint (PV-1) that accounts for the direct and indirect costs of the acquisition program but this refers to specific costs of a system, which is too specific for the ICD-stage.

4.4.3 Too Much Information or Not Enough?

"I would suggest that the fundamental "information problem" faced by managers is not too little information but too much information." (P. Senge, 1990)

"In order to have good judgment about boundaries, an architect must keep up to date with a multitude of issues and topics." (Lim, 1998)

In addition to missing information, there are other limitations to DoDAF. The first challenge we came across in creating DoDAF viewpoints for a notional ground vehicle is achieving a balance between highlighting the key operational activities of the capability requirement and capturing excessive information with too much specificity.

The operational and capability viewpoints (OVs and CVs) are initially generated during the Capabilities Based Assessments (CBA). (US Department of Defense, 2015) The CBA is expected to cover "the spectrum of strategically relevant operational scenarios" so the viewpoints will be scoped to just these scenarios. A CBA can take anywhere from six months to several years so it is understandable that only the typical and major scenarios will be analyzed. For a notional ground vehicle capability requirement, Major Combat Operations (MCO) and Irregular Warfare (IrW) would be considered to be the most relevant scenarios. These scenarios would include operational activities such as OP 3 "Employ Fires" and OP 1 "Conduct Operational Maneuver" in the OV-5a.

However, the absence of additional scenarios like Limited Interventions or Peace Operations results in the exclusion of a broad set of tasks such as TA 5.9.1 "Conduct Foreign Humanitarian Assistance" or OP 8.6 "Provide Population Security". This creates a gap in the analyzable information in DoDAF. An experienced stakeholder in JCIDS would certainly have an understanding that a ground vehicle capability would involve these tasks. This understanding may be derived from experience or formal training but it cannot be attained from DoDAF alone. The current architecting process of using a few scenarios will not paint a complete picture of how a capability requirement is employed.

One of the questions posed by an FCB stakeholder was, "What other missions and functions would a solution for an identified gap address besides the need indicated by the organization seeking the validated requirement?" This is a difficult question to answer with DoDAF if each capability requirement is only tied to a select group of scenarios and omitting its employment in other scenarios. A simple query in the DoDAF database could answer this question but this information would not be available.

On the other hand, capturing every possible operational activity is costly and inefficient. DoDAF does have the flexibility to capture relevant activities beyond the scenarios analyzed during the CBA. For example, multiple OV-5a's can depict the operational activities pertaining to several scenarios. This inherent flexibility allows the architect to capture unlimited information. Although, this specificity provides a lot of information, it can also render the capability requirement indistinguishable from another capability requirement. The OV-5a, for a capability requirement as general as a ground vehicle, could encompass nearly every Universal Joint Task. The capabilities of a ground vehicle can entail every operational scenario that falls within the spectrum of combating terrorism to humanitarian assistance. This can create an over abundance of information, especially without the existence of a prescribed method for distinguishing ancillary activities from the primary ones.

4.4.4 What is a Capability?

If the concepts in the mind of one person are very different from those in the mind of the other, there is no common model of the topic and no communications.
- Taylor 1995 (Rechtin & Maier, 2009)

Another challenge of capturing information with DoDAF is the ambiguity in defining military concepts. Clear definitions are essential in enterprise architecture to ensure a common understanding. However, harmonizing the vocabularies of the joint and service sectors has historically been a challenge and its effects are noticeable in DoDAF. A key example of this is in defining a capability. See Table 12 for the nuanced differences in each definition.

Finding a unified description of a capability is challenging. JP 3-0 alludes to a military capability as its "people, organizations, and equipment." (US Department of Defense, 2011) Alternatively, the J-6 WMA Architecture Development standards simply define capabilities by the Joint Capability Areas. (Deputy Director Cyber and C4 Integration, 2015)

Although the January 2016 version of JP 1-02 does not provide a definition of a capability, the JCIDS manual defines a capability as "the ability to complete a task or execute a course of action under specified conditions and level of performance." It is important to note that a task is not conducted in isolation but rather for a purpose or objective. The DM2 capability data group takes this into account and adds it to its definition of a capability: "the ability to achieve a desired effect under specified standards and conditions through combinations of means and ways to perform a set of tasks." (DoD Deputy CIO, n.d.-b) However, the CBA guide recognizes that this definition invites even more confusion:

> *Under this definition, you need to know (and accept) the definition of an effect, a standard, a condition, a mean, a way, and a task, and be able to describe all of them to define a capability. Plus, the ability to achieve a particular effect using different combinations of ways and means implies that these abilities are different capabilities.* (JCS J-8, 2009)

DoDAF viewpoints and the ICD each describe capability in largely different ways. See Table 12. These varying descriptions of a capability pose a challenge for the stakeholders in the JCIDS enterprise. One of the questions from those within the FCB was what other missions will be impacted by the identified capability requirement. Currently, the seven viewpoints required at the ICD-stage do not explicitly trace the capability to a mission or desired effects. This differs from the FCB's expected description of a capability. The disconnect in defining a capability poses problems in JCIDS, whose ultimate purpose is to identify capability requirements.

Capability Requirements as defined by:

JCIDS Manual	ICD (Capability Requirements and Gaps/Overlaps section)	DoDAF (CV-2, CV-3, CV-6)	J-6 WMA Architecture Development Standards
"the ability to complete a **task** or execute a **course of action** under specified **conditions** and level of **performance**"	Initial objective value of the capability requirement **operational attributes** necessary to achieve mission objectives with moderate operational risk	Name of the capability, which may be a **JCA**	Capabilities are defined by the **JCAs**. Capabilities used in WMA architectures must either be a JCA (integrated) or map to the related JCA (federated).
	Assessment of **operational implications of risk**	**Attributes/measures** of the capability (optional)	
	Associated **JCAs, task, conditions, standards from UJTs/Service tasks, ROMO, timeframe under consideration**	**Hierarchy** of capabilities that describes the relationship between each (optional)	
	Difference between the intial objective value and current or planned operational performance levels	The planned **phases** of the capability	
	Capability requirements that **overlap** with current or planned capabilities	The operational **activity** (UJT) associated with the capability	
	The impact of the capability **gap** or **overlap** on the operational context		

Table 12: Descriptions of a Capability and Capability Requirements

4.4.5 Summary

This section examined the limitations of DoDAF in providing holistic information about a capability requirement to the JCIDS stakeholders. The analysis indicates that DoDAF can capture an unlimited amount of information about a single capability requirement through its flexible data fields and non-prescriptive nature. This can provide stakeholders a very full understanding about the single capability requirement in isolation.

However, it is difficult to apply systems thinking and develop a holistic understanding of the complexity when there are differing capability requirement architectures in the capability portfolio. One can certainly use DoDAF to create enterprise level architectures to conduct this analysis. Applying prior experiential knowledge or accessing additional studies can also reveal the linkages between key features such as missions, operational activities, and operational attributes. These linkages, however, are not readily available with the DoDAF viewpoints required at the ICD-stage. Table 13 depicts the main points captured in each section.

<table>
<tr><th>DoDAF Limitations</th><th>Related ICD/CML Information</th><th>Implications</th></tr>
<tr><td>Optional or unstructured data fields</td><td>• Range of military operations/scenario/concepts
• Conditions</td><td rowspan="2">• Missing data fields can be compensated with fit-for-purpose data fields or unstructured data fields like "Image Description"
• However, this increases visibility into one capability requirement but does not provide a holistic understanding across the capability portfolio because some pieces of information are not included in the standard set of required data fields.</td></tr>
<tr><td>No data field for certain pieces of information</td><td>• Measured desired effects
• Measurable operational outcomes
• Associated threat products
• Operational risk
• Estimated resources required/available/unavailable
• Strategic guidance
• Resource/Investment Information</td></tr>
<tr><td>No standard way to use multiple viewpoints or the "capability type" data field when capturing information about other relevant capabilities</td><td>• Non-materiel capabilities
• Threat capabilities
• Enabling capabilities
• Capability Gap
• Capability Overlap
• Capabilities of partner nations/other agencies</td><td>• The absence of a standard way to capture other relevant capabilities detracts from the stakeholders' ability to quickly attain a systems perspective about the capability requirement</td></tr>
<tr><td>Viewpoints are tied to a select group of missions or scenarios</td><td>• Range of military operations/scenario/concepts</td><td>• Other relevant scenarios or missions in a capability portfolio is more difficult to analyze with DoDAF</td></tr>
<tr><td>The framework's flexibility can capture an over abundance of information</td><td></td><td>• Capturing all of the relevant information with an architecture framework is costly
• A capability requirement can become indistinguishable from another</td></tr>
<tr><td>Varying definitions of "capability"</td><td></td><td>• Stakeholders who have differing definitions of a capability will expect different pieces of information pertaining to the capability. This makes it challenging to have a standard way of capturing the necessary information when the definition is not clearly defined. This leads to additional difficulty in making the required information available to all and providing easy accessibility to the information inside a capability portfolio.</td></tr>
</table>

Table 13: Summary of Key Findings

5. Conclusion

During the front-end analysis of the ICD-stage, stakeholders in the JCIDS enterprise are ensuring that the identified capability requirement is needed in the capability portfolio. JCIDS brings together stakeholders and gets a commitment on what is needed for the joint force at the ICD-stage. This is a vital step since a validated capability requirement provides the conceptual underpinning for the rest of the acquisition phases. A validated ICD indicates that there is a recognized capability need and a capability solution can be further pursued. The use of systems thinking based on accurate information is essential at this stage to enhance the visibility and traceability of the joint capability portfolio. This will inform the stakeholders in the process of certifying that the capabilities are not unnecessarily redundant, are interoperable, and are a priority for the joint force.

In order for this analysis to be successful, stakeholders must have traceability and visibility of the information about the capabilities in the joint portfolio. This information will drive the stakeholders' decision-making calculus during the validation process. "Commanders make and implement decisions based on information. Information imparts structure and shape to military operations. It fuels understanding and fosters initiative." (Department of the Army Headquarters, 2012) Although this is in reference to operations, the importance of information can certainly be applied to the JCIDS enterprise.

However, accumulating, processing, and analyzing this large amount of information is no easy task. Capabilities exist in each of the military services and every agency in the Department of Defense while threats and external factors can change at a faster rate than our systems are designed to make policies and regulations around them. The Functional Capabilities Boards have been one way to manage this wide array of capabilities by focusing on particular functions. The danger of this design is that information can be kept in functional silos, which can prevent capabilities from being validated from a holistic perspective.

Information about capabilities is largely contained in capability documents and studies or in the experience of the stakeholders themselves. Stakeholders who have experience in the JCIDS process develop an inestimable amount of knowledge about their specific area of capabilities. However, with personnel turnover and variability in experience, this can result in a thinning of institutional knowledge when the information source is solely dependent on the stakeholders' experience and documents.

Although the JCIDS process requires "flexibility and creativity" in its execution, there is also a need for a level of repeatability in acquisition decision-making. (JCS J-8, 2009) (Griendling & Mavris, 2011) DoDAF can supplement a stakeholder's experiential knowledge and information documents and provide a consistent base of visible and traceable information. It can be a way to structure and organize information to provide a common understanding of the joint capability portfolio. This thesis examined how well the information contained in the DoDAF viewpoint data fields can provide that holistic understanding and foster systems thinking during the ICD-stage of the validation process.

The early stages of analyzing a need differ from the traditional systems engineering of a particular system because it has to take a broader holistic approach than an analysis of an individual system. DoDAF has not been required at this front-end analysis stage in the past. As a structured way of capturing information, DoDAF holds promise for not only quicker information retrieval but for providing broader understanding across multiple capabilities. This thesis assumed that this was possible and examined whether the structured information contained in DoDAF provide the JCIDS stakeholders more visibility and traceability of the capability portfolio. This study used a matrix to determine the alignment between the information contained in the ICD and in DoDAF to answer this question.

The findings indicate that the current viewpoints are adequate in describing a single capability requirement as well as an ICD or any other free-text document. DoDAF is flexible and non-prescriptive so the viewpoints capture information like resource flows well. DoDAF's origins as an architectural framework for technical systems is evident in its ability to systematically capture detailed information such as how information, people, and materiel flow between consuming and producing performers in an operation (OV-2). DoDAF (OV-5a, CV-2, CV-6) also captures the Associated Joint Tasks and Joint Capability Areas in more organized detail than free-text. These are like the performance parameters of a specified system presented during the CDD/CPD stage. They are well defined because the information is limited to a particular system.

However, DoDAF alone does not provide a holistic understanding of the capability portfolio. A stakeholder who is validating the capability requirement would have to supplement DoDAF with knowledge of past studies (CRA, CGA, CBA, etc.) and capability documents (ICD, CDD, CPD) to uncover interdependencies and traceable information.

The current set of viewpoints have a predetermined set of data fields that leave out critical information such as associated strategy documents and missions or operations. These predetermined data fields are useful because a stakeholder is guaranteed access to these pieces of information for all of the capabilities in the portfolio. However, the data fields do not cover some aspects of the capability requirement that may be important for validation like related threat capabilities. A stakeholder who wants to use DoDAF to conduct analyses can miss key relationships between data elements across viewpoints and across the capability portfolio because of missing information. This was evident in how there are no specific data fields for secondary operational activities or particular viewpoints to denote threat and enabling capabilities.

DoDAF can also restrain a holistic perspective because of its non-prescriptive nature. For example, there is no uniform way to capture and distinguish threat capabilities from the primary ones. There is a fit-for-purpose data field that provides a way for the architect to capture any information not denoted by the data fields. However, it is not a structured or standardized so there are multiple ways a stakeholder can use DoDAF to represent the same information. This makes accessing information or comparing capabilities to determine any overlaps, redundancies, and interoperability more difficult.

Capability needs are too fuzzy and important conceptual information collected during the ICD stage is too fungible and vast for DoDAF to completely capture alone. There needs to be a clear scope of information for an architecture framework. For example, a notional ground vehicle capability requirement can be used for multiple desired operational effects but capturing all possible desired effects is not realistic. This, in turn, creates difficulty in comparing other capability requirements in the portfolio that may be addressing the same desired effects. A completely integrated capabilities portfolio requires having all the information on hand and DoDAF alone falls short of providing that visibility.

5.1 Recommendations

Intermediary steps can be taken to address the aforementioned limitations so that more structured and traceable information is available to the stakeholder. The first recommendation is to provide standard guidance in capturing capability gaps/overlaps, threat capabilities, non-materiel capabilities and enabling capabilities with multiple viewpoints or utilizing the "capability type" data field. Currently, this information is only contained in the ICD. Additional CV-2's and OV-5a's could describe threat capabilities to the notional ground vehicle like kinetic attacks with an EFP or enabling capabilities like inter/intra theater maneuver capabilities. Additional guidance on the degree of specificity and using multiple viewpoints would encapsulate this information in structured form and enhance the availability of this information for the stakeholder to use to determine other capabilities that address a similar or new and emerging threat. It could also be used to determine other capabilities that require the same enabling capability. A combination of viewpoints of the capability requirements, enabling capabilities, and threat capabilities could develop a more robust knowledge base of the capability portfolio for architecture-based analysis.

Furthermore, the addition of the CV-1 and OV-3 would provide a fuller picture of the capability during front-end analysis of the JCIDS process. The CV-1 includes specific data fields for “Desired Effect”, “Measure of Effect”, and “Condition”, which are pieces of information not currently available in the other seven viewpoints. This information would enable the stakeholder to answer questions like what other capabilities can partially deliver a particular effect or operate in certain conditions. Currently, this information would not be in the architecture repository for JCIDS at the ICD-stage.

The OV-3 also contains additional information that would add more detail to the operational context of the capability requirement. This viewpoint would provide traceability to specific operations or missions that were used to determine the capability requirement. It also includes data fields for the measure of conditions and attributes of the resource flows. Additionally, unlike the OV-3, the OV-2 has no standardized method or data field to connect a resource flow to an operational activity.

This information in aggregate would increase the information aligned with the ICD from 4 to 10 information elements. The architectural representation of the other capabilities like threat, non-materiel, and enabling capabilities would also increase alignment. This decreases the need to rely on sifting through capability documents to determine traceability to information such as missions, conditions, or desired effect. Instead, more of the analysis can be based on knowledge repositories with DoDAF architectures. Future ICDs that enter JCIDS could be supported by a more detailed foundation of information. There would be more visibility into existing capabilities and parallel capabilities in development

Although these recommendations are not a panacea to the problems facing the DoD acquisition enterprise, it can be a step towards unlocking more information about the capability requirement contained in unstructured texts to be able to conduct more thorough and quicker analyses by the stakeholders.

5.2 Limitations and Future Work

Further work is necessary to validate these findings. Interviews with the certifying and endorsing offices and the stakeholders in the FCB could provide more perspectives on the information provided by DoDAF. Also, interviewing the sponsors of the capability requirements could reveal how the information elements are used and developed during their capability requirement identification process. Additionally, a wider adoption of DoDAF is necessary for it to truly provide a common understanding of capability requirements in the JCIDS enterprise. Further work should investigate the cost and benefits of familiarizing JCIDS stakeholders with DoDAF. Tracking any improvements or degradations in information sharing would also illuminate how stakeholders use DoDAF.

Additionally, this thesis only examined the applicability of DoDAF by assuming a structured framework would be a faster way to conduct analyses. This assumption could be tested in future work by examining how much of the analysis hinges on reading through documents, prior knowledge of documents/capabilities, and using DoDAF. Some stakeholders may have a higher dependency on DoDAF than others so it may be more helpful to capture more specific information needs.

Moreover, an investigation into the relationship between the missing information during the ICD-stage and the technical risks during the CPD/CDD stage could reveal the strength of the linkages between the earlier viewpoints and the performance parameters in the system viewpoints.

This thesis builds on a semantic analysis project, which consists of the author, MIT research team, and the DoD Joint Staff. Semantic analysis will potentially extract meaning from unstructured text like the ICD, CBA and other studies. Instead of only capturing information content with DoDAF, semantic analysis would attempt to capture the thoughts and meaning being conveyed by the writers of the documents. The concepts captured by DoDAF are meant to express an idea to the stakeholder who will be able to relate it to his or her own experience and interpret it to produce an understanding that will drive decision-making. However, as this thesis has demonstrated, the pathway from expression to knowledge is not always well defined when the concept can be extended to take on a variety of meanings. This can lead to a variety of interpretations by the stakeholder, which can lead to inconsistent analyses and decisions. Semantic analysis could potentially provide a more comprehensive data structure that could convey the meaning behind the information elements and address the problem of a slow requirements process and lack of understanding of the interdependencies in the capability portfolio.

The challenges facing the larger acquisition enterprise cannot be solved with only tangential improvements but with rather holistic approaches. This purpose of this thesis was to provide an analysis of DoDAF as an information source, which can be an addition to broader approaches to improving our acquisition enterprise.

Appendix A: Past Successful Acquisition Programs in the Department of Defense

Capability	System	Comment
Sea-based airpower for fleet defense, strike, surveillance, etc.	Aircraft carriers	Developed despite lack of interest by and opposition of the "Battleship Navy"
Projection of ground forces from ships into defended land areas	Amphibious operations	Conceived and developed by visionary Marine colonel
Precision fires	Laser-guided bomb (LGB) and joint direct attack munition (JDAM)	Resisted consistently by Service PPBE processes and those adhering to a peculiarly strict interpretation of acquisition regulations
Maritime operations in littoral areas	Littoral combat ship	Scorned initially but championed by Chief of Naval Operations
Detection and tracking of moving ground targets	J-STARS	Moved directly into field from R&D during first Gulf War
Unmanned surveillance and targeting	Global Hawk and Predator	Resisted by Air Force
Tactical mobility	Stryker	Championed by Army Chief of Staff and controversy
Strike, penetration	F-117, B-2	Championed by DDR&E and Secretary of Defense and a few Air Force and Navy leaders
Early warning of ballistic-missile attack	DSP (early warning satellites)	Resisted by most, due to legacy programs, but supported by Air Force Chief of Staff
Submarine-based nuclear retaliatory forces	SSBNs (nuclear0armed ballistic-missile submarines)	Imposed on Navy by president
Assured dissemination of emergency action messages, even in surprise attack	Strategic nuclear command and control during Cold War	Involved largely separate system, thereby avoiding many sources of friction

Table 14: Past Successful Acquisition Programs. Source: (Davis et al., 2008)

Appendix B: Key Concepts of General Systems Theory

Subsytems or Components: A system by definition is composed of interrelated parts or elements. This is true for all systems—mechanical, biological, and social. Every system has at least two elements, and these elements are interconnected.

Holism, Synergism, Organicism, and Gestalt: The whole is not just the sum of the parts; the system itself can be explained only as a totality. Holism is the opposite of elementarism, which views the total as the sum of its individual parts.

Open Systems View: Systems can be considered in two ways: (1) closed or (2) open. Open systems exchange information, energy, or material with their environments. Biological and social systems are inherently open systems; mechanical systems may be open or closed. The concepts of open and closed systems are difficult to defend in the absolute. We prefer to think of open-closed as dimension; that is, systems are relatively open or relatively closed.

Input-Transformation-Output Model: The open system can be views as a transformation model. In a dynamic relationship with its environment, it receives various inputs, transforms these inputs in some way, and exports outputs.

System Boundaries: It follows that systems have boundaries which separate them from their environments. The concept of boundaries helps us understand the distinction between open and closed systems. The relatively closed system has rigid, impenetrable boundaries; whereas the open system has permeable boundaries between itself and a broader supra-system. Boundaries are relatively easily defined in physical and biological systems, but are very difficult to delineate in social systems, such as organizations.

Negative Entropy: Closed, physical systems are subject to the force of entropy which increases until eventually the entire system fails. The tendency toward maximum entropy is a movement to disorder, complete lack of resource transformation, and death. In a closed system, the change in entropy must always be positive; however, in open biological entropy—a process of more complete organization and ability to transform resources—because the system imports resources from its environment.

Steady State, Dynamic Equilibrium, and Homeostasis: The concept of steady state is closely related to that of negative entropy. A closed system eventually must attain an equilibrium state with maximum entropy—death or disorganization. However, an open system may attain a state where the system remains in dynamic equilibrium through the continuous in-flow of materials, energy, and information.

Feedback: The concept of feedback is important in understanding how a system maintains as an input into the system, perhaps leading to changes in the transformation process and/or future outputs. Feedback can be both positive and negative, although the field of cybernetics is based on negative feedback. Negative feedback is information input which indicates that the system is deviating from a prescribed course and should readjust to a new steady state.

Hierarchy: A basic concept in systems thinking is that of hierarchical relationships between systems. A system is composed of subsystems of a lower order and is also part of a supra-system. Thus, there is a hierarchy of the components of the system.

Internal Elaboration: Closed systems move toward entropy and disorganization. In contrast, open systems appear to move in the direction of greater differentiation, elaboration, and a higher level of organization.

Multiple Goal-Seeking: Biological and social systems appear to have multiple goals or purposes. Social organizations seek multiple goals, if for no other reason than that they are composed of individuals and subunits with different values and objectives.

Equifinality of Open Systems: In mechanic systems there is a direct cause and effect relationship between the initial conditions and the final state. Biological and social systems operate differently. Equifinality suggests that certain results may be achieved with different initial conditions and in different ways. This view suggests that social organizations can accomplish their objectives with diverse inputs and with varying internal activities (conversion processes).

Source: (Kast & Rosenzweig, 1972)

Appendix C: Capability Mission Lattice

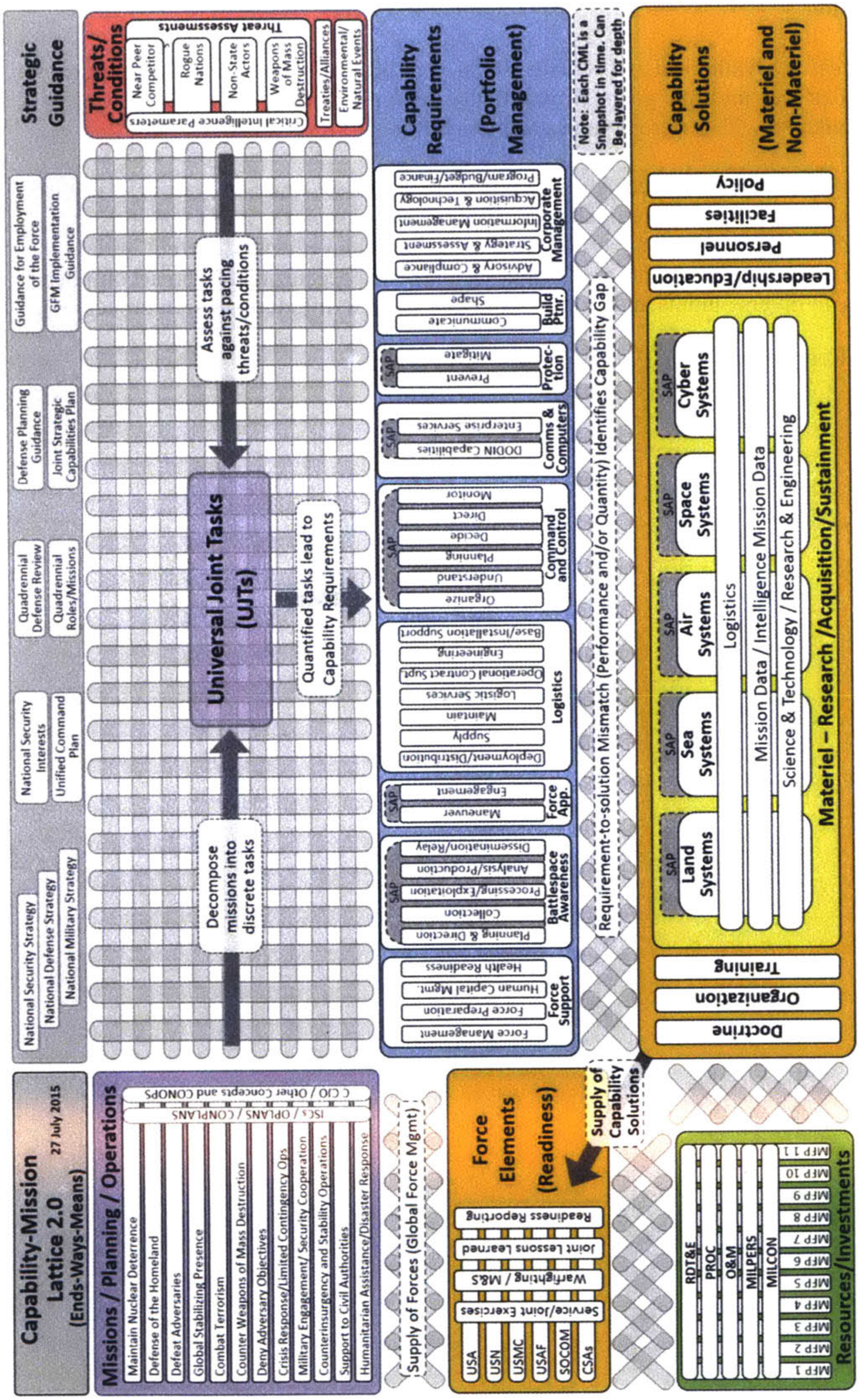

Figure 29: Capability Mission Lattice

Appendix D: Stakeholder Decomposition

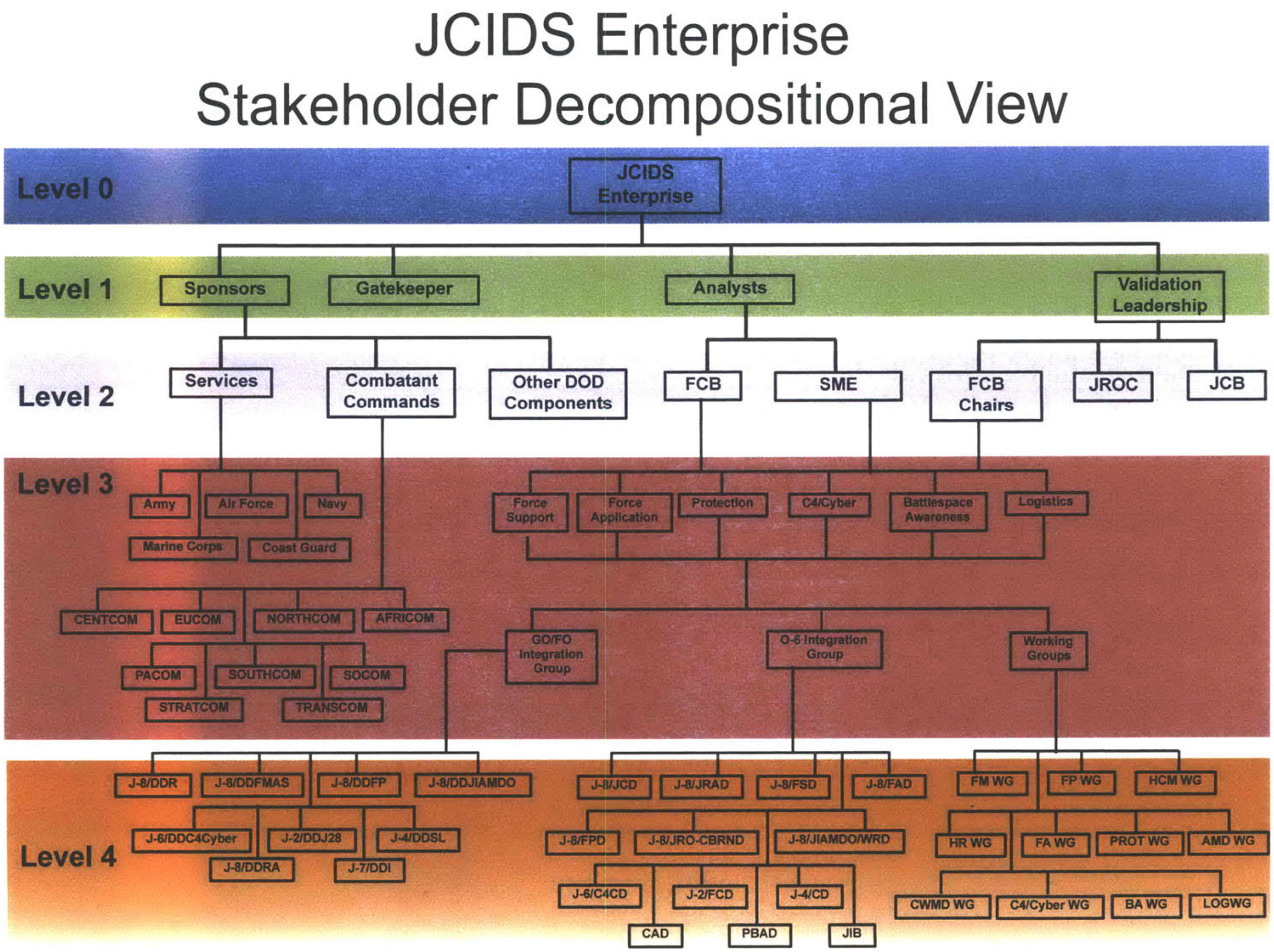

Figure 30: Stakeholder Decomposition

Appendix E: DoDAF-ICD Full Matrix

DoDAF Viewpoints		OV-1 High-level Operational Concept Graphic				OV-2 Operational Resource Flow Description						OV-4 Organizational Relationship Chart					OV-5a Operational Activity Decomposition Tree							CV-2 Capability Taxonomy									CV-3 Capability Phasing										CV-6 Capability to task Mapping	
ICD Sections	ICD Elements / DoDAF Elements	1 Image Name	2 Image (Text) Description	3 Alternate Text	4 Relationship Type	5 Producing Performer Name	6 Operational Resource Flow Name	7 Consuming Performer Name	8 Consuming Location	9 Relationship Type	10 Producing Location	11 Superior Organization Name	12 Organization Name/ Subordinate Organization Name	13 Organization Location	14 Relationship Type	15 Hierarchy Type Description	16 Superior Operational Activity Name	17 Operational Activity Name	18 Operational Activity Type	19 Operational Activity Description	20 Hierarchy Type Description	21 Relationship Type	22 Ordinal	23 Capability / Capability Requirement Name	24 Capability Type	25 Capability Version Number	26 Capability Description	27 Capability Measure	28 Capability Measure Type	29 Hierarchy Type Description	30 Relationship Type	31 Capability Release Date	32 Capability Name	33 Phase Name	34 Phase Start Date	35 Phase End Date	36 Relationship Type	37 Superior Capability Name	38 Capability Time Start Date	39 Capability Time End Date	40 Organization Name	41 Phase Description	42 Operational Activity Mapped to Capability	43 Relationship Type
Operational Context	Traceability to missions/operations/scenarios/concepts		o	o																																								
	Relevancy of a CBRN environment																									o																		
	Timeframe for IOC and FOC of the capability requirement																															x	x	x	x	o	o	o	o	o	o		
	Required measurable operational outcomes																																											
	Effects required to achieve the operational outcomes																																											
	Contribution to the joint/multinational warfighting force		o	o		x	x	x	o	o	o	x	x	o	o	o																												
	Other enabling capabilities required	x	x			o	o	o									m	m	m					m	m	m	m	m	m	m	m	m												
Threat Summary	Associated threat products																																											
	Threat capabilities in the expected operational environment	x	x			o	o	o				m	m	m	m	m	m	m	m					m	m	m	m	m	m	m	m	m												
Capability Requirements and Gaps/Overlaps	Initial objective value of the operational attributes																										ra	ra																
	Assessment of operational implications of risk																																											
	Associated JCAs																							x	x	x	x																x	o
	Associated UJTs and service tasks																x	x	x	o	o																						x	o
	Associated conditions																									o																		
	Associated ROMO		o	o																																								
	Associated timeframe																																x	x	x									
	Gap operational performance levels																							m	m	m	m	m	m	m	m	m												
	Overlap with current or planned capabilities																							m	m	m	m	m	m	m	m	m												
	The impact of the gap or overlap on the operational context																																											
Assessment of Non-Materiel Approaches	Non-materiel approaches to close or mitigate capability gap											m	m	m	m	m								m	m	m	m	m	m	m	m	m												
	Remaining capability gaps that require materiel solution																							m	m	m	m	m	m	m	m	m												
	Capabilities of partner nations/US gov. agencies/DoD Comp.											m	m	m	m	m								m	m	m	m	m	m	m	m	m												
	Assessment of quantity changes of current capability solutions																																											
	Intelligence community interoperability and assessment											m	m	m	m	m								m	m	m	m	m	m	m	m	m												
Final Recommendations	Non-materiel recommendations that are part of the materiel solution																							m	m	m	m	m	m	m	m	m												
	Non-materiel recommendations independent of materiel solution																							m	m	m	m	m	m	m	m	m												
	Materiel recommendations (new, replace, upgrade)																																											
	The impact of the gap or overlap on the operational context																																											
	Technologies with potential to mitigate capability gap																																											
	Acceptance of operational risk																																											
	Estimated resources required/available/unavailable																																											

Figure 31: DoDAF-ICD Full Matrix

Appendix F: DoDAF-ICD Matrix (Aligned Information)

ICD Sections	DoDAF Viewpoints / DoDAF Elements / ICD Elements	OV-1 High-level Operational Concept Graphic				OV-2 Operational Resource Flow Description						OV-4 Organizational Relationship Chart				
		Image Name	Image (Text) Description	Alternate Text	Relationship Type	Producing Performer Name	Operational Resource Flow Name	Consuming Performer Name	Consuming Location	Relationship Type	Producing Location	Superior Organization Name	Organization Name/ Subordinate Organization Name	Organization Location	Relationship Type	Hierarchy Type Description
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Operational Context	Timeframe for IOC and FOC of the capability requirement															
	Contribution to the joint/multinational warfighting force		o	o		x	x	x	o	o	o	x	x	o	o	o
Capability Requirements and Gaps/Overlaps	Associated JCAs															
	Associated UJTs and service tasks															
	Associated timeframe															

ICD Sections	DoDAF Viewpoints / DoDAF Elements / ICD Elements	OV-5a Operational Activity Decomposition Tree							CV-2 Capability Taxonomy								
		Superior Operational Activity Name	Operational Activity Name	Operational Activity Type	Operational Activity Description	Hierarchy Type Description	Relationship Type	Ordinal	Capability / Capability Requirement Name	Capability Type	Capability Version Number	Capability Description	Capability Measure	Capability Measure Type	Hierarchy Type Description	Relationship Type	Capability Release Date
		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Operational Context	Timeframe for IOC and FOC of the capability requirement																
	Contribution to the joint/multinational warfighting force																
Capability Requirements and Gaps/Overlaps	Associated JCAs								x	x	x	x					
	Associated UJTs and service tasks	x	x	x	o	o											
	Associated timeframe																

ICD Sections	DoDAF Viewpoints / DoDAF Elements / ICD Elements	CV-3 Capability Phasing										CV-6 Capability to task Mapping	
		Capability Name	Phase Name	Phase Start Date	Phase End Date	Relationship Type	Superior Capability Name	Capability Time Start Date	Capability Time End Date	Organization Name	Phase Description	Operational Activity Mapped to Capability	Relationship Type
		32	33	34	35	36	37	38	39	40	41	42	43
Operational Context	Timeframe for IOC and FOC of the capability requirement	x	x	x	x	o	o	o	o	o	o		
	Contribution to the joint/multinational warfighting force												
Capability Requirements and Gaps/Overlaps	Associated JCAs											x	o
	Associated UJTs and service tasks											x	o
	Associated timeframe		x	x	x								

Figure 32: DoDAF-ICD with Aligned Information

Appendix G: DoDAF-ICD Matrix (Partially Available Information)

DoDAF Viewpoints / DoDAF Elements / ICD Elements

ICD Sections	ICD Elements	OV-1 High-level Operational Concept Graphic: 1 Image Name	2 Image (Text) Description	3 Alternate Text	4 Relationship Type	OV-2 Operational Resource Flow Description: 5 Producing Performer Name	6 Operational Resource Flow Name	7 Consuming Performer Name	8 Consuming Location	9 Relationship Type	10 Producing Location
Operational Context	Other enabling capabilities required	x	x			o	o	o			
Threat Summary	Threat capabilities in the expected operational environment	x	x			o	o	o			
Capability Requirements and Gaps/Overlaps	Gap operational performance levels										
	Overlap with current or planned capabilities										
Assessment of Non-Materiel Approaches	Non-materiel approaches to close or mitigate capability gap										
	Remaining capability gaps that require materiel solution										
	Capabilities of partner nations/US gov. agencies/DoD Comp.										
	Intelligence community interoperability and assessment										
Final Recommendations	Non-materiel recommendations that are part of the materiel solution										
	Non-materiel recommendations independent of materiel solution										

ICD Sections	ICD Elements	OV-4 Organizational Relationship Chart: 11 Superior Organization Name	12 Organization Name/ Subordinate Organization Name	13 Organization Location	14 Relationship Type	15 Hierarchy Type Description	OV-5a Operational Activity Decomposition Tree: 16 Superior Operational Activity Name	17 Operational Activity Name	18 Operational Activity Type	19 Operational Activity Description	20 Hierarchy Type Description	21 Relationship Type	22 Ordinal
Operational Context	Other enabling capabilities required						m	m	m				
Threat Summary	Threat capabilities in the expected operational environment	m	m	m	m	m	m	m	m				
Capability Requirements and Gaps/Overlaps	Gap operational performance levels												
	Overlap with current or planned capabilities												
Assessment of Non-Materiel Approaches	Non-materiel approaches to close or mitigate capability gap	m	m	m	m	m							
	Remaining capability gaps that require materiel solution												
	Capabilities of partner nations/US gov. agencies/DoD Comp.	m	m	m	m	m							
	Intelligence community interoperability and assessment	m	m	m	m	m							
Final Recommendations	Non-materiel recommendations that are part of the materiel solution	m	m	m	m	m							
	Non-materiel recommendations independent of materiel solution	m	m	m	m	m							

ICD Sections	ICD Elements	CV-2 Capability Taxonomy: 23 Capability / Capability Requirement Name	24 Capability Type	25 Capability Version Number	26 Capability Description	27 Capability Measure	28 Capability Measure Type	29 Hierarchy Type Description	30 Relationship Type	31 Capability Release Date
Operational Context	Other enabling capabilities required	m	m	m	m	m	m	m	m	m
Threat Summary	Threat capabilities in the expected operational environment	m	m	m	m	m	m	m	m	m
Capability Requirements and Gaps/Overlaps	Gap operational performance levels	m	m	m	m	m	m	m	m	m
	Overlap with current or planned capabilities	m	m	m	m	m	m	m	m	m
Assessment of Non-Materiel Approaches	Non-materiel approaches to close or mitigate capability gap	m	m	m	m	m	m	m	m	m
	Remaining capability gaps that require materiel solution	m	m	m	m	m	m	m	m	m
	Capabilities of partner nations/US gov. agencies/DoD Comp.	m	m	m	m	m	m	m	m	m
	Intelligence community interoperability and assessment	m	m	m	m	m	m	m	m	m
Final Recommendations	Non-materiel recommendations that are part of the materiel solution	m	m	m	m	m	m	m	m	m
	Non-materiel recommendations independent of materiel solution	m	m	m	m	m	m	m	m	m

ICD Sections	ICD Elements	CV-3 Capability Phasing: 32 Capability Name	33 Phase Name	34 Phase Start Date	35 Phase End Date	36 Relationship Type	37 Superior Capability Name	38 Capability Time Start Date	39 Capability Time End Date	40 Organization Name	41 Phase Description	CV-6 Capability to task Mapping: 42 Operational Activity Mapped to Capability	43 Relationship Type
Operational Context	Other enabling capabilities required	m	m	m	m								
Threat Summary	Threat capabilities in the expected operational environment	m	m	m	m								
Capability Requirements and Gaps/Overlaps	Gap operational performance levels												
	Overlap with current or planned capabilities												
Assessment of Non-Materiel Approaches	Non-materiel approaches to close or mitigate capability gap												
	Remaining capability gaps that require materiel solution												
	Capabilities of partner nations/US gov. agencies/DoD Comp.												
	Intelligence community interoperability and assessment												
Final Recommendations	Non-materiel recommendations that are part of the materiel solution												
	Non-materiel recommendations independent of materiel solution												

Figure 33: DoDAF-ICD with Partially Available Information

Appendix H: DoDAF-ICD Matrix (Unavailable Information)

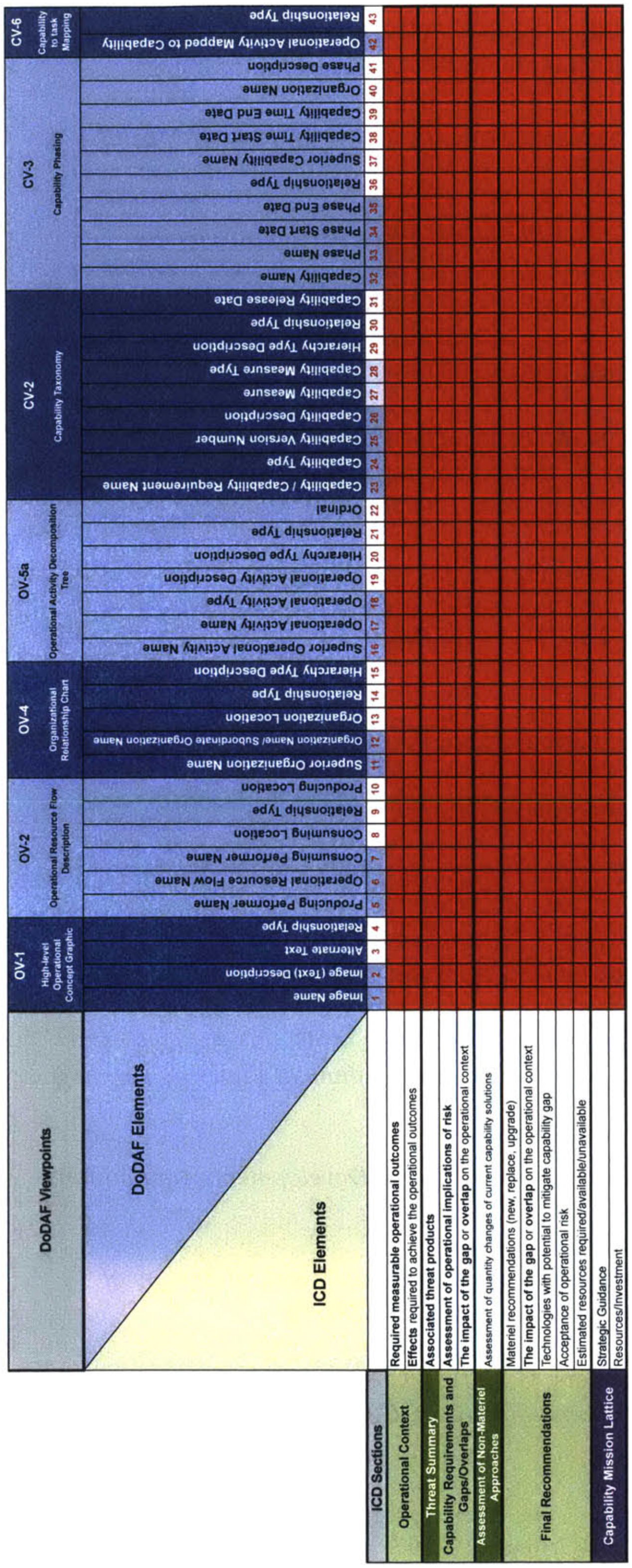

Figure 34: DoDAF-ICD Matrix with Unavailable Information

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