Applying Semantic Technology to Early Stage Defense Capability Planning Analysis Based on JCIDS Artifacts

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Agenda

• Goals of JCIDS Semantic Architecture Framework Research
• Joint Capability Enterprise Architecture
• Exploratory Experiments
• Systematizing Method for Manual Use
• Leveraging Semantic Technology
• Next Steps
JCIDS (Joint Capabilities Integration and Development System) 
A Systematic Process for Warfighters to Develop, Validate, and 
Control Capability Requirements for Acquisition

LIMITATIONS OF CURRENT JCIDS PROCESS
• Necessarily Document-Driven 
• DODAF Architecture Not Fully Integrated 
• Silos of Information by Capability/Program and Date of Writing

MIT Research Goals
- Unlock docs into data
- Connect text info to architecture content
- Bridge info silos
- Apply inference to extend understanding

Joint Capability Enterprise Architecture (JCEA)
System of Systems Complexity is Inherent in JCIDS

Value Proposition for Capability-Based Planning (Aldrich Study, 2004)

![Diagram showing the flow from Strategy to Desired Effects to Capabilities to Fielded Systems]

Capability-Based Planning Works Backwards from Goals to Factor Out Systems Needed
Not as Simple and Linear as it Looks

Investment decisions must be made years or decades in advance
... within limited and changing budget constraints
... to assure that Services will have the capabilities on hand
... to supply resources to combatant commanders
... to be dynamically integrated into joint task forces
... to achieve effects needed to accomplish future missions
... in support of national strategy

Question: How to Manage the Inherent Complexity of the Problem?

- Combinatorics of the solution space vs. need to limit scope of each system
- Dynamic effects of decision lead times and necessity for integration
- Uncertainty on critical factors affecting the design
e.g., strategy, threats, budgets, technology, related program outcomes
Views
JCIDS Docs, DODAF and SMEs each capture partial information on underlying reality as of a point in time.

Ontology defines slots that structure data extracted from documents and DODAF. Meanings in the vocabulary are explicit and shared across the enterprise. Ontology also defines relationships among data elements in the JCEA model.

Current State and Planned Future States
- Strategic Guidance
- Missions — Threats
- Force Capabilities
- Functions and Tasks
- Materiel Systems
- Technology

Joint Capability Enterprise Architecture (JCEA)

Ontology defines slots that structure data extracted from documents and DODAF. Meanings in the vocabulary are explicit and shared across the enterprise. Ontology also defines relationships among data elements in the JCEA model.
Defining Semantics: Empirical Review of Documents

• Broad review of 88 unclassified sample JCIDS documents to build familiarity, recognize patterns, and discern ‘ground truth’

• Detailed deep-dive into three capability documents (ICD, CDD, CPD)
  1) what **SHOULD** be in document?
  2) what **WAS** in document?
  3) what is **ESSENTIAL** in document?

• Documents selected for deep-dive experiment:
  – 3 different stages of development (ICD, CDD, CPD)
  – 3 different functional areas staffed by different FCBs
  – All in Air domain with documents staffed in 2007-2009

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**ICD**
Logistics

- Joint Future Theater Lift (JFTL)
  Move cavalry with armor

**CDD**
Force Application

- Joint Air-to-Ground Missile (JAGM)
  Replace HELLFIRE, TOW and Maverick

**CPD**
Battlespace Awareness

- Extended Range UAS (MQ 1C)
  Dedicated support to Division

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**Found implicit interdependencies across separately staffed capabilities.**
Framing a Joint Capability Enterprise Architecture: Capability Categories – Joint Capability Areas

“To support needs definition, gap and excess analysis, major trade analyses, and capabilities planning, DoD’s capabilities must be divided into manageable groups, or capability categories.” – Aldrich Study (2004)

2005 – Original JCAs
- 4 top level categories (operational, functional, domain, institutional)
- 22 Tier 1 with 240 subordinate JCAs

2007 – Revised JCAs
- 9 Tier 1 JCAs, 6 Tiers
- Functional only
- Aligned with FCBs
- Operational dimension removed

Empirical Observations from Docs
- Most JCIDS docs use multiple Tier 1 JCAs
- JCAs are used as a framework for describing operational attributes of capabilities not just desired effects

Conclusions
- JCAs alone are insufficient to categorize capabilities
- A multidimensional category structure is preferable to a single taxonomy
Framing a Joint Capability Enterprise Architecture: Joint Staff Capability Mission Lattice (CML)

Basic ontology from Capability Mission Lattice has been expanded to include elements required in JCIDS Manual and taxonomies/frameworks in use.
Using C-M-L Ontology to Find Interdependencies

The C-M-L based ontology can help identify interdependencies between systems that are not apparent in documents or with current taxonomies.
Systematizing Semantic Architecture Framework
JCIDS Ontology Design Task

Central goal: Define a semantic knowledge base that captures the portfolio of capabilities & gaps early in development

Ontology and architecture frame the knowledge base
- Ontology also captures and connects essential military and requirements process subject domain knowledge

Requirements documents provide the content
- Text of documents (interpreted against ontology)
- Structured information in tables and DODAF artifacts attached in structured form suitable for machine use
- Images such as OV-1 (hard to extract info from)

Additional content will come from SME annotations as an ontology-based knowledge base is put into use

Data captured and organized in a semantic architecture framework will continue to be accessible and reusable as SMEs rotate in and out and as circumstances change
# Overview of ICD Ontology Design based on 2015 JCIDS Manual and Capability-Mission-Lattice

## Operational Context
- Time Frame
- Strategic Guidance
- ROMO
- Operational Concepts

### Threats
- Threat context
- Expected operational environment
- Current threats
- Anticipated threats

## Capability Req’ts
- Define Capability Requirements in Lexicon of:
  - Time Frame
  - ROMO
  - Org / Unit Type
  - JCAs
  - UJTL Tasks
  - Service Tasks
  - Conditions
  - Supported and supporting tasks

### Operational Attributes
- Metrics
- Objective Values

## Capability Gaps
- Match to Current Capabilities
  - Legacy fielded
  - In Development
  - Rapidly fielded
  - Predecessor system if recap or next gen

### Identify Gaps for each Operational Attribute (O/A):
- Current capability O/A metric value
- Gap from current to objective value

### Operational Impact of Gap

## Recommendations
- Materiel Solutions Suggested for AoA
  - Evolution of fielded system
  - Replacement or recap of fielded system
  - Transformational capability solution

- Technology Leverage to reduce Operational Risk
  - Functionality
  - Affordability

- DOTmLPF-P Recommendations
# Example: JFTL ICD Extracted Capability Gaps

<table>
<thead>
<tr>
<th>Gap Num</th>
<th>Functional Concept</th>
<th>Gap Description</th>
<th>Reason for Gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IOM</td>
<td>Inability to operate into austere, short, unimproved landing areas</td>
<td>Proficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inability to perform operational maneuver with medium weight armored vehicles and personnel or reposition medium weight armored vehicles and personnel by airlift</td>
<td>Proficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inability to reposition forces with combat configured medium weight armored vehicles via air</td>
<td>Proficiency</td>
</tr>
<tr>
<td>2</td>
<td>OMSD</td>
<td>Inability to operate into austere, short, unimproved landing areas</td>
<td>Proficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deliver cargo weights equivalent to the weight of combat configured medium weight armored vehicles to austere, short, unimproved landing areas.</td>
<td>Proficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conduct precision air delivery of supplies, to the point of need/point of effect over strategic and operational distances with required velocity.</td>
<td>Proficiency</td>
</tr>
<tr>
<td>3</td>
<td>DMSS</td>
<td>Inability to operate into austere, short, unimproved landing areas</td>
<td>Proficiency</td>
</tr>
<tr>
<td></td>
<td>DES</td>
<td>Deliver cargo weights equivalent to the weight of combat configured medium weight armored vehicles to austere, short, unimproved landing areas.</td>
<td>Proficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Conduct precision air delivery of supplies, to the point of need/point of effect over strategic and operational distances with required velocity.</td>
<td>Sufficiency</td>
</tr>
<tr>
<td>4</td>
<td>JFEO</td>
<td>Inability to transport forces over strategic and operational distances to points of need by passing traditional PODs, and to operate on austere, short, unimproved landing areas.</td>
<td>Proficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inability to deploy and employ forces, with combat configured medium weight vehicles, via air across the global battle space from strategic, operational and tactical distances.</td>
<td>Proficiency</td>
</tr>
</tbody>
</table>
# Example: Compare Gap Operational Attributes

## Gaps by Functional Concept

<table>
<thead>
<tr>
<th>Operational attribute</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Operational attribute values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo handling</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>No MHE</td>
</tr>
<tr>
<td>Combat Radius</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>As determined in AoA</td>
</tr>
<tr>
<td>Cruise Speed</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>As determined in AoA</td>
</tr>
<tr>
<td>Fuel efficiency</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Fuel efficiency must be greater than that of the C-130J</td>
</tr>
<tr>
<td>In-flight Refuel Speed (as Receiver)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>As required</td>
</tr>
<tr>
<td>Payload Weight &amp; Dimensions</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Combat configured medium weight armored vehicles (Army ground combat vehicles, Stryker)</td>
</tr>
<tr>
<td>Precision Delivery</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>~25 – 50 km of objective</td>
</tr>
<tr>
<td>Secure Communications</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Interoperable, secure, encrypted, voice and data, beyond line of sight/over the horizon</td>
</tr>
<tr>
<td>Self Deploy</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>2,400 nm</td>
</tr>
<tr>
<td>Survivability</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Ability to effectively integrate with future joint forces for threat suppression/mitigation in a low to medium threat environment</td>
</tr>
</tbody>
</table>
Capturing Implicit Information

Documents reviewed often have **inconsistent data**
- Most have current JCAs; some have 2005 JCAs; some have JFCs
- JCAs often used for multiple purposes
- Some have UJTs; most do not

SMEs can make sense of documents despite gaps & other inconsistencies

Ontology-based data capture – combined with inference rules – can allow automation to **follow same logic used by SMEs**

Connecting to other Knowledge

*Example of how can semantic inference can help:*
- Joint Future Theater Lift (JFTL) ICD has no UJTs
- JFTL ICD references JP 3-17 (Air Mobility Operations) and Joint Forcible Entry by name
- Joint Forcible Entry (JFEO) defined by JP 3-18
- UJTL database ties UJTs to definitional docs JP 3-17 and JP 3-18
- By combining these fragments of information, UJTs for JFTL can be inferred

Semantic architecture provides the benefits of capturing the true capability provided by a system by interpreting text within a document.
Semantic Ontology Experiments

Developed an **ICD ontology** containing 150 data slots based on draft 2015 JCIDS Manual, C-M-L, and other frameworks

**Manual text extraction** experiments
- 6 ICDs as sources, 3 SMEs perform extraction
- Into Excel form structured by the ontology
- Reliability varied: some data were consistently extracted; other data inconsistent

A parallel project showed potential for applying natural language processing to **automate text extraction**

SMEs built a **practical relational database** by focusing on the more consistent areas and for wider sample of JCIDS documents

Experiment showed that **DODAF views can be generated** from data extracted from JCIDS documents

**MIT continuing research is focused on formalizing and systematizing methods to extend the scope and value of the results**
Research on Technologies and Methods for Storing and Accessing Semantic Knowledge

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1) <strong>Documents</strong> repository (current as-is state)</td>
<td></td>
</tr>
<tr>
<td>2) <strong>Relational</strong> or spreadsheet data</td>
<td></td>
</tr>
<tr>
<td>3) <strong>DODAF architecture</strong> structured data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– New 2015 JCIDS Manual requires DODAF views to be submitted with requirements documents for validation</td>
</tr>
<tr>
<td></td>
<td>– Research is exploring how to connect text document content to DODAF data and artifacts</td>
</tr>
<tr>
<td>4) <strong>Semantic data store with inference rules</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Facts stored as <strong>RDF Triples</strong> (subject-predicate-value)</td>
</tr>
<tr>
<td></td>
<td><strong>Flexibility</strong> from capturing facts in small pieces</td>
</tr>
<tr>
<td></td>
<td>– Facts can be combined in multiple ways by <strong>inference rules</strong> and <strong>semantic query</strong></td>
</tr>
</tbody>
</table>
Semantics Technology Proof-of-Concept Prototype Design Overview

**Ontology** – design based on
- JCIDS Manual
- Capability-Mission-Lattice
- other terminology frameworks

**Semantic Technology Tools**
- Built on Semantic Web industry standards such as OWL, RDF, SPARQL & cyber-security
- Includes tools for working with ontology and data
- Highly flexible data store and semantic query/search
- Technology used allows research results to be ported to other COTS product sets

**DODAF Generation Tools**
- COTS/GOTS tools, such as NoMagic/MagicDraw/CAMEO
- UPDM interface (probable)
- Python to convert data format
Connections in Capability Requirements Ontology

Value of capability comes from effect produced

Mission Operational Context
- Mission Effects
- Performing Org/Unit
- Operational Activity
- Operational Attributes
- Mission Conditions
- Threats to Mission
- • Universal Joint Task
- • Joint Capability Area

Capability Requirement
- Desired Effects
- Operational Activity
- Threats to Capability
- Capability Conditions
- Operational Attributes
- • Universal Joint Task
- • Joint Capability Area

Operational Attribute
- Generic Operational Attribute
- Metric for Operational Attribute
- Required Initial O/A Objective Value
- Current Attribute Value
- Difference

Category Frameworks
- Service & Universal Joint Tasks
- JCA – Joint Capability Areas

Strategic Guidance

Mission Areas

Operational Concept

Expected Operational Environment

Threat Context

Operational Attribute

Metric for Operational Attribute

Current Capability

Required Initial O/A Objective Value

Current Attribute Value

Time Frame
JCIDS Semantic Architecture Framework

Enables Capability Enterprise Architecture
- Multi-dimensional grouping of capabilities by category framework properties
- Logically deriving capability dimensions and similarities from operational attributes
- Capturing and retaining SME knowledge across silos and over time

Identifies Capabilities Dependencies
- Tracing capabilities to assumptions, conditions, and threats
- Tracking interfaces and connections among capabilities
- Inferring dependencies based on effects produced and effects needed

Supports Systems Engineering
- Trade space identification for capability requirements planning
- Trade space exploration at the capabilities portfolio level

MIT Research is investigating and developing methods to apply semantic technology to Joint Capability Enterprise Architecture
Goals for Semantic Architecture (2016)

Unlocking Knowledge

- Decompose documents into conceptual elements independent of language, to enable translation of across terminology, frameworks, and taxonomies.
- Identify implicit interconnections and interdependencies across separately staffed capability requirements (including different time periods, different functional areas, and different services or components).
- Connect text to architecture to create a more complete picture in a form suitable for inference.
- Generate DODAF artifacts from ontology-based data extracted from text documents.

Supporting Decisions

- Provenance: Maintain time-varying continuity of requirements across development stages and across separate branching threads.
- Drill down: Make conceptual connections across different levels of architecture (e.g. SoS vs. Systems, KPPs vs. DODAF) as designs evolve.
- Track changes to assumptions (e.g., strategic direction, mission profiles, threats, operational concepts, technology available).
- Support systems engineering methods such as Trade Space Exploration and Epoch-Era Analysis.
References


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