Software System Acquisition Problem Areas
Requirements Always High on the List

- **ACAT I Acquisition Programs** under scrutiny (GAO 04-393) – significant issues published
- **Boehm** : ‘Reasons Why Programs Fail’ – Inadequate Requirements a major causal factor
- **Sandish Report and others**: Inadequate requirements source of cost and schedule overruns and performance shortfalls

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<th>Project Management Best Practices</th>
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<th>Software Architecture</th>
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Little Evidence of Requirements Engineering in place
Classic Requirements Management
As Operations Requested It

As Engineering Designed It

As Procurement Ordered It

As Accounting Paid For It

As Plant Maintenance Installed It

What the Soldier Wanted!
The Capability Turn in Requirements Development: A Domain-Centered Approach

Software quality in digitized systems depends on how well the software represents and is responsive to the domain contexts in which the systems operate.

A capability driven approach* builds on domain centered approaches – capabilities are defined wrt to a context containing multiple domains.

User-driven, domain-driven & capability-driven approaches to software intensive system acquisition all point in a similar direction –

* Capability driven approaches in the military stem from the Joint Capabilities Integration and Development System (JCIDS) created by the Chairman of the Joint Chiefs of Staff (CJCS)
The Capability Turn in Requirements Development: Difficulties

In the US military, capability driven approaches are difficult to implement due to

- the huge numbers of people involved and their very different perspectives (e.g., warfighter vs. bureaucrat vs. technologist)
- the rapidly changing and uniqueness of threats
- the pace of information technology.

From analysis of 10s of 1000s of Problem and Trouble Reports it appears that capability driven approaches are not informing the software as well as they could.

- Software problems are not stated in terms of capabilities being adversely affected
- Software solutions do not refer to how enablement of capabilities can be improved
Overcoming Difficulties for the Capability Turn: 
A Framework for Capability Engineering

The aim of Capability Engineering (CE) is to meet the challenges capability & domain driven approaches face.

CE is the mutual formulation of joint capabilities and acquisition requirements for multiple

- platforms
- systems/subsystems that work with or in these platforms.

CE supports traceability and validation of requirements specifications from capabilities

The Capability Engineering Framework (CEF) provides knowledge management support for CE.

The CEF identifies, annotates and organizes exemplary practices.
The Five Dimensions of CEF

The five CEF *Dimensions* organize and document support for “good practices” in capability engineering:

1. **Organization** – the infrastructure of virtual organizations, which are multiple organizations using both on-line and face-to-face interaction in an integrated fashion.

2. **Process** – the production of work products and ultimately the product itself, especially to processes that are inter-organizational.

3. **Information** – (a) finding patterns of information through text and data mining; (b) structuring information via domain & quality models across stakeholders; and (c) organizing information flow to support building and validating material solutions.

4. **Evaluation** – assuring quality of both product and process, and especially the tie between the two.

5. **Learning** – the integration of evaluations and other forms of feedback at the enterprise level (both PEO and SoS or FoS) into actionable improvements.

Current CEF work focuses on the **Information** dimension in support of **Battle Command (BC)** Capability Portfolio Management (CPM).
Information Dimension: Benefits

There are several benefits of capability & domain driven BC software design.

1. Traceability, and therefore validation, of multiple software systems and systems of systems is facilitated.
   - Currently, traceability is missing and validation is reduced to verifying mission threads
   - S &T opportunities are under appreciated because of insufficient mutual understanding between warfighter and software technologist

2. Composing system of systems to enable capabilities that none of the systems alone can enable will be better understood.
   - Current capability documents provide a partial picture of how systems can or should fit together
   - There is no common ground for reasoning about system composition.

3. Capability Portfolio Management across programs in a PEO and across PEOs will be facilitated.
The Information Dimension: Sources

In order to represent the domains guiding capability driven software,

- sources of domain expertise and information have to be tapped
- processes for domain modeling must be established.

In the military, much of the expertise is written down in the form of

=> **1. Joint Capability Areas**
   2. Concept Documents
   3. Doctrine
   4. Capability Documents (ORDs, ONS, ICDs, CDDs, CPDs…)
   5. Information Support Plans (ISPs)
   6. User Functional Descriptions
   7. Problem and Trouble Reports
   8. Shortfalls and Warfighter Outcomes
   9. Exercise After Action Reviews,
      Independent Evaluation Results
Joint Capability Area Focus:
Battle Command Capability

**Command & Control**

**Organize**
- Establish & maintain unity of effort w/ mission partners
  - Develop Trust
  - Estab & Cultivate Rel w Msn Partners
  - Estab & Cultivate Rel w Partner Orgs

**Structure organization to mission**
- Define structure
- Assess Staff Capabilities
- Delegate Authority
- Identify Capabilities Needed
- Integrate Capabilities
- Estab Commanders' Expectations

**Foster organizational collaboration**
- Estab Collaboration Policies
- Estab Collaborative Procedures

**Understand**
- Organize Information
- Develop Knowledge and Situational Awareness
- Share Knowledge and Situational Awareness

**Planning**
- Analyze problem
  - Analyze Guidance
  - Review Rule Set
  - Review Situation
  - Determine Need for Action
  - Prepare Estimates

- Apply situational understanding
  - Assess Available Capabilities
  - Evaluate Environment
  - Determine Vulnerabilities
  - Determine Opportunities

- Develop strategy
  - Determine Force Readiness
  - Determine Resources
  - Adapt Strategy
  - Align Strategy
  - Develop Assumptions
  - Develop Objectives
  - Determine End State
  - Review Existing Plans

- Develop courses of action
  - Understand Objectives
  - Develop Options
  - Establish Selection Criteria

- Analyze courses of action
  - War game courses of actions
  - Compare courses of actions

**Decide**

**Manage risk**
- Validate Targets
- Formulate Crisis Assessment
- Provide Friendly Force Combat Identification
- Direct Consequence Management

**Select actions**
- Select course of action
- Select Plan
- Terminate

**Establish rule sets**
- Establish intent and guidance
  - Establish Priorities
  - Establish Standards
  - Establish Rule Sets

**Intuit**
- Recognize Key Triggers
- Modify Actions

**Direct**

**Communicate intent and guidance**
- Issue Estimates
- Issue Priorities
- Issue Rule Sets
- Provide CONOPS

**Task**
- Synchronize Operations
- Synchronize Execution across Phases
- Issue Plans
- Issue Orders

**Establish metrics**
- Establish Performance Measures
- Establish Effectiveness Measures

**Monitor**

**Assess compliance with guidance**
- Assess Employment of Forces
- Assess Manner of Employment

**Assess effects**
- Assess Battle Damage
- Assess Effects of Deception Plan
- Assess Munitions Effects
- Assess Performance
- Assess Re-Engagement Requirement
- Assess Operational Effects of Strategic Communications

**Assess achievement of objectives**
- Assess guidance
### Joint Capability Area Focus: Battle Command Capability 2

#### Net-Centric

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<tr>
<th>Information Transport</th>
<th>Wireless</th>
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#### Enterprise Services

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<td>Data Storage</td>
<td>Data Processing</td>
<td>COI Services</td>
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#### Net Management

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<th>Optimized network functions &amp; resources</th>
<th>Deployable, scalable &amp; modular networks</th>
<th>Spectrum Management</th>
<th>Cyber Management</th>
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#### Information Assurance

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<th>Protect Data and Networks</th>
<th>Monitor IA Status</th>
<th>Prevent Network Attack</th>
<th>Protect Data from Modification</th>
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<th>Detect &amp; Respond to Attacks</th>
<th>Detect &amp; Respond to Event</th>
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#### Battlespace Awareness

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<th>Collection</th>
<th>Signals</th>
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<th>Correlate</th>
<th>Convert</th>
<th>Exploit</th>
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<th>Intel Spt to Situational Understanding</th>
<th>Indications &amp; Warnings</th>
<th>Intel Spt to Targeting, FP &amp; IO</th>
<th>Battle Damage Assessment</th>
<th>Science &amp; Technology</th>
<th>Counter Intelligence</th>
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<th>Environment</th>
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**Net-Centric**

- Information Transport
  - Wireless
  - Wired

**Enterprise Services**

- Core Enterprise Services
  - Collaboration
  - Mediation
  - Discovery
  - Messaging

- Information Sharing/Computing
  - Data Storage
  - Data Processing
  - COI Services

**Net Management**

- Optimized network functions & resources
- Deployable, scalable & modular networks
- Spectrum Management
- Cyber Management

**Information Assurance**

- Secure Information Exchange
  - Ensure Authorized Access
- Protect Data and Networks
  - Monitor IA Status
  - Prevent Network Attack
  - Protect Data from Modification

- Respond to Attack / Event
  - Detect & Respond to Attacks
  - Detect & Respond to Event
Mapping systems to system functions enables traceability to Joint & Army-wide operational capabilities.

The Joint Common System Function List (JCSFL) is cumbersome & manually applied by JSFL experts.

Successful mapping may be facilitated by automated support that could leverage the JCSFL.

Engage with PEOs to evaluate current proposed JCSFL mappings & viability of automated support.

Proposed manual mappings include AMPS, DCGS, FBCB2, FCS, GCCS, JWARN, Prophet, SaaS, TAIS.
Capability to System Mapping:
Concept Maps & Domain Modeling

Both automated and interactive analyses will be performed on collections of documents chosen from each information source.

*Automated content analysis* will produce *concept maps* of selected information sources.

Concept maps will be *interpreted and aligned* to the extent possible.

The aim is to find conceptual links among maps of the information sources that will support *domain modeling* of BC contexts.

The BC context currently being investigated is Army Aviation.

The current focus is to align BC enabling systems as specified by PEO Aviation with planning capabilities as specified by TRADOC.
Methodology: Content Analysis & Concept Maps

Semi-automated content analysis uses automated text analysis tools to identify recurring concepts & clusters of concepts:

- Concepts are synonyms of strongly related co-occurring terms identified in automatically generated affinity lists
- Concept Clusters are collections of co-occurring concepts
  - more strongly related to each other than to concepts in other clusters
  - named by automatic selection of the concept most strongly related to other concepts in the cluster

Concept Clusters are represented graphically as Venn diagrams.

- concepts labeling dots are in concept clusters represented as circles
- dots can be linked by lines whose brightness represents frequency of co-occurrence
- dots can appear in the overlap of two (or more) circles
- circle size based on distribution of concepts included in the circle (not importance)
  - brightness represents interconnectedness of concepts in the circle
Content Analyses and The Role of Interpretation

Map overlays can delimit groups of concepts from more than one concept cluster according to human interpretation, e.g., BC, BC enablers, helicopters

Interpretation also depends on posing and answering specific questions,

• **Question:** Are there concepts that trace back from documentation of BC software intensive systems to documentation of BC capabilities?

• **Traceability Potential:** *Route* and its role in BC planning is one such concept.

The maps shown require additional interpretation in collaboration with combatants, domain experts, requirements and capability developers and testers.
Aligning Concept Maps: On the Way to Domain Modeling

Shared Kernel (e.g., route)

Joint & Army Doctrine

ORNs, AARs, Gaps, Shortfalls, Lessons Learned

ORDs, Capability Documents, UFDs & ISPs

Interpreting *Route* in Army Aviation Concept & Doctrine

**Operations Concept (2008):**

- *Route* plays a role in BC capabilities enabled by software intensive systems and is used in Army Aviation operations
- More specifically, *route* is used in C2 planning and to a lesser extent in other BC activities and BC enabling systems
- Though several specific helicopters are mentioned, *route* links to two – AH-64D & ARH-70

**Operations Doctrine (2008 draft 2007):**

- *Route* plays a role in an Aircraft’s flight & C2 operations, and also wrt planning
- *Route* & planning link to BC concepts but are somewhat separated from BC discussion
- *Route* links to discussion of specific helicopters – not the specific aircraft but concepts discussed with these, e.g., radar, infrared systems & visualizing
TP 525-7.15 (Concept Capability Plan for Army Aviation Operations 2015-2024):

Concept Clusters

- Link Concept Cluster to KJ: Column Ia.
TP 525-7.15 More Magnified – relation of route to BC and non-BC at 50%
BC and Route in Army Aviation Doctrine Operations at 22%
Interpreting *Route* in Army Aviation C2 Doctrine and Planning System DFD

**C2 Doctrine (2002):**

- *Route* plays a role in air defense operations & control of the aircraft in airspace
- It is used in planning and A2C2 and to a lesser extent in the command coordination hierarchy
- Planning is within the BC overlay that includes concepts of BC & its enablers
- No mention of specific helicopters

**Planning System Desired Functions Document (2007):**

- The focus is on *route*’s role in planning capability & the aircraft’s flight/mission
- Also in focus are information systems as capability enablers and Data as rendered in charts
- The overlay of BC concepts is contained in the Plan concept cluster, as is route
- Closely related overlays specifically refer to BC enabling (BCE) software intensive systems & helicopters
BC in Army
Aviation Doctrine
C2 at 30%

Command Coordination Hierarchy

Battle Command
BC in Army Aviation Doctrine C2 at 100%
Planning System
Desired Functions Doc (DFD) with overlays but no concepts shown
Planning System DFD concept clusters showing routes & its links at 17%
Planning System DFD overlays grouping platforms, systems & BC concepts in relation to routes at 100%
Analysis of Army Aviation BC Documentation:
Planning System STRs

Planning System Development STRs (2008):

• *Route* is thematic and consists of points created by a user in dialog with the software modules SAGE & AWE manipulating messages & files

• *Routes* are imported from files, created, selected and displayed

• Data changes and changing values occur and are linked to *route*

• All the above are implicated in errors

Planning System Post-Development STRs (2008):

• *Route* consists of points graphically displayed in dialog with SAGE, though change is associated with *route* not data

• Graphics and dialog are now thematic

• File, message and user are most associated with error.

• Imported waypoints are now closely associated with *route* as is Mission Planning
Planning System
Development STRs – Route links at 10%
Planning System Development STRs – Route conceptual context at 100%
Planning System Post Development STRs – Route concepts/context
Analysis of Army Aviation BC Documentation: Planning System STRs– Route as Domain Concept

The Planning System STRs are not capability focused, and rather given to buttonology, but they do make contact with BC contexts and domains through route and user.

*Route* is a domain concept that needs to be represented via domain modeling of BC Aviation contexts informing software development, acquisition and testing.

We have shown that TRADOC pamphlets, doctrine and DFDs could be utilized so that capability, domain and user centered testing has impact on prioritizing maintenance, refinement and evolution of systems.

We are planning meetings with combat and material developer domain experts to identify more concepts like *route* that will be sufficient for building

- domain models in each sphere of expertise
- aligning the models in the Army Aviation BC context
Summary: Establishing Shared Conceptual Structures

Operational Military Information Flow

- Capture, Analyze, Synthesize, Externalize
- Socialize
- Analyze, Synthesize, Externalize

Conceptual Framework

Doctrine & Training

 Acquisition, Testing & Budgeting
Thank you for your attention!

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