Integrating the Systems Engineering "V" in a Systems of Systems

3 March 2009

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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• Employ a Mission-based SE in an SoS environment approach to complete the (traditional) Materiel-based SE “V” (SE-V) in the development of DOTMLPF Capabilities for the warfighter.

• Retaining Mission, Task, and Human Dimension context throughout the Capability lifecycle provides assessment results
  – in traditional Materiel-base terms and
  – their relationships and contributions both direct and indirect to warfighting operational performance and mission effectiveness.

• Mission-based SE in SoS is an extension of MBT&E compatible with the
  – OSD/P&R directives for reporting METL-based Readiness
  – Joint GEL directive for certifying deploying units,
  – JCIDS Capability-based Acquisition
  – DoD SE Guide for SoS, and
  – DOT&E JTEM framework and procedures.

METL: Mission-Essential-Task-List with measures, conditions and standards to accomplished a desired end result
SoS: Systems of Systems
SE “V”: Top-Down definition and design then Build followed by Bottom-Up integration, and verification
DOTMLPF: Doctrine, Organization, Materiel, Leadership, Personnel, and Facilities
HD: Army Human Dimension initiative in three behavior domains -- Social, Cognitive, and Physical
MBT&E: ATEC Mission-based Test & Evaluation framework, procedure, and complexity constraint strategies
GEL: Joint Guidance for Employment of Forces for unit certification prior to deployment
P&R: OSD Personnel & Readiness
JTEM: Joint Test & Evaluation Methodology
• **System (S)** - A functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements; that group of elements forming a unified whole [JP 1-02 & JP 3-0].

• **Capability** - is the ability to achieve a desired effect under specified standards and conditions through combinations of ways and means to perform a set of tasks [CJCS, 2007(2)].

• **Family of Systems (FoS)** - a set of systems that provide similar capabilities through different approaches to achieve similar or complementary effects [CJCS, 2007(1)].

• **System of Systems (SoS)** - is defined as a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities [DoD, 2004(1)].

* Taken from the DoD SE Guide for SoS
• Virtual SoS* – Group lacks a central management authority and a centrally agreed upon purpose for the system-of-systems.

• Collaborative SoS* – Group component systems interact more or less voluntarily to fulfill agreed upon central purposes.

• Acknowledged SoS* – Group has recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the systems are based on collaboration between the SoS and the systems.

• Directed SoS* - The group, an integrated system-of-systems, is built and managed to fulfill specific purposes. It is centrally managed during long-term operation to continue to fulfill those purposes as well as any new ones the system owners might wish to address. The component systems maintain an ability to operate independently, but their normal operational mode is subordinated to the central managed purpose.

* Taken from the DoD SE Guide for SoS
Systems Engineering “V” (1 of 3)
Systems of System Engineering (2 of 3)

INPUTS
- ORD, O&O, ASR, SEP, CDD

System of System Specification
- Prime Item & CI Development Specs

Preliminary Design

CI / CSCIs

Component Verification

Build

Verification

Test

Analysis and Simulation

Integration and Verification

Army Operational Validation

System of System Verification

Subsystem Integration Verification

Taken from 21 Jun2 20005 FCS Review to DAB
SE in SoS Environment Issues (3 of 3)

INPUTS
ORD, O&O, ASR, SEP, CDD

JCIDS Req't's
System of System Specification
Prime Item & CI Development Specs
Preliminary Design
CI / CSCIs
Component Verification
Build

Verification

T&E Oversight
Army Operational Validation
System of System Verification
Subsystem Integration Verification
System Integration Verification

Operational Context
Independent Specifications

Operational Context
Not Retained for Assessments

Operational Context
Not Retained for Assessments

Taken from 21 Jun 2005 FCS Review to DAB
MBT&E Building Block

**Capability**¹ – The ability to achieve a **desired effect** [or result, outcome, or consequence of a task²] …

– under specified **standards and conditions**
– through a combination of **means and ways**
– to perform a set of tasks.

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1. CJCSI 3170.01F, May 2007
2. Taken from JP 1-02, Mar 2007, definition of effect.
MBT&E - Task Hierarchy

MBT&E Framework – v2

**Process/Products**

- Commander’s Task to Subordinates
  - Mission Analysis
    - Higher Commander’s Intent
    - Restated Mission
    - Task to Subordinates

**Capability**

- Desired Result
  - Mission Analysis
    - Higher Commander’s Intent
    - Restated Mission
    - Task to Subordinates
  - Systems Engineering
    - Functional Baseline
    - Allocated Baseline
    - Product Baseline

- Desired Mission Task Results
  - Operations (Mission Tasks)
    - UJTLs
    - Service TLs
    - Implied Tasks

- Desired System Task Results
  - System-of-Systems Tasks
    - Service TLs
    - Implied Tasks
    - Collective/Individual Tasks

- Desired System Performance Results
  - System Performance
    - Functions (shall do)
    - "shall be's"

**High Level Tasks/Results**

- Commander’s Task to Subordinates
- Mission Analysis
- Systems Engineering
- Operations (Mission Tasks)
- System-of-Systems Tasks
- System Performance

**Tasks/Results Specific to System**

- Desired End State
- Mission Task Capability
- SoS Task Capability
- System Performance

**System Functions**

- Transition to Allocating Mission Means
- Transition to Allocating SoS Means
- Transition to Allocating Materiel Means

**Capability = Set of Tasks + Desired Result**
MBT&E - Task Hierarchy

MBT&E Framework – v2

**Process/Products**

- Commander’s Task to Subordinates
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  - Higher Commander’s Intent
  - Restated Mission
  - Task to Subordinates
- Commander’s Task to Subordinates
- Mission Analysis
  - Higher Commander’s Intent
  - Restated Mission
  - Task to Subordinates
- System Attributes
- Systems Engineering
  - Functional Baseline
  - Allocated Baseline
  - Product Baseline

**Capability**

- Desired End State
- Mission Task Capability
  - Operations (Mission Tasks)
    - UJTLs
    - Service TLs
    - Implied Tasks
- Desired Mission Task Results
- SoS Task Capability
  - System-of-Systems Tasks
    - Service TLs
    - Implied Tasks
    - Collective/Individual Tasks
- Desired SoS Task Results
- System Performance
  - Functions (shall do)
  - "shall be's"
- Desired System Performance Results

Essence:
What must be accomplished and Why

Implementation:
DOTMLFP
How and Who

DOTMPF
Component
• **ATEC Mission Based Test & Evaluation** is consistent with
  - OSD P&R directives for reporting METL-based Readiness
  - Joint GEF certification for Deployment of Operational Forces
  - JCIDS Capability based Acquisition
  - DoD Systems Engineering guide for Systems of Systems (SE for SoS)
  - DOT&E Joint Test & Evaluation Methodology (JTEM)

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**Based on Generic, General Purpose Measures/Conditions/Standards**

- TPFData List
- TO&E
- C-METL
- OSD P&R Readiness

**Based on Mission, Situation Specific Measures/Conditions/Standards**

- TPFDeployment Data
- MTOF
- D-METL
- Joint GEF Certification

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TPFDL: Time Phased Force Data List for deployment planning

TPFDD: Time Phased Force Deployment Data for deployment execution

TO&E: Table of Organization and Equipment for a standing unit

MTOF: Mission Task Organized Force (modeling & simulation term)

C-METL: Core METL defined by Army Force Generation (ARFORGEN) for commonality between units of the same type

D-METL: Directed METL defined by Army Force Generation (ARFORGEN) for a unit with specific deployment orders

GEL: Joint Guidance for Employment of Forces for unit certification prior to deployment

P&R: OSD Personnel & Readiness directives for METL-based readiness reporting

JCIDS: Joint Capability Integrated Development System
## MBT&E Procedure

19 steps divided into 5 major purpose areas.

- 1 Pre-step to collect information.

### UNDERSTAND THE MISSION
- 4 steps to understand the military operations, tasks, task capabilities and mission context.

### UNDERSTAND THE SYSTEM
- 2 steps to understand the components and attributes of the materiel system-of-systems.
- 1 additional step to understand the mission and system linkages.

### DESIGN THE T&E
- 7 steps to design the T&E given the mission and system understanding.

### DETERMINE THE RESULTS
- 3 steps to generate, collect, analyze, and evaluate the data.

### REPORT THE RESULTS
- 1 step to format and report the results.
Adaptation to Complete SE-V

• N steps divided into 5 major purpose areas.
  • 1 Pre-step to collect information.

- UNDERSTAND THE MISSION
  • 4 steps to understand the military operations, tasks, task capabilities and mission context.

- UNDERSTAND THE SPEC’s
  • 2 steps to understand the Context-Independent specifications of the materiel system-of-systems.
  • 1 additional step to understand the mission and system specifications linkage (retain Context-Dependence link).

- DESIGN THE System
  • SE steps to design the system to the specifications given the Mission, Task, HD context understanding.

- DETERMINE THE RESULTS
  • 3 steps to generate, collect, analyze, and evaluate the data.

- REPORT THE RESULTS
  • 1 step to format and report the results.
If Human Dimension (HD) is the “System”

Human Dimension is parsed by three behavioral domains: Social, Cognitive, and Physical

**Social Behavior (9)**
- Affects, Emotions, and Moods
- Cultural Awareness (CA) & CA Training
- Ethics & Values / Morals & Beliefs
- Group Dynamics / Group Interactions
- Interpersonal Relations
- Leadership & Leadership Training
- Networking
- Personnel Issues / Recruitment & Retention
- Quality of Life

**Cognitive Behavior (12)**
- Attention & Memory
- Cognitive Workload
- Comprehension / Understanding
- Creativity & Imagination
- Decision Making
- Learning
- Motivation
- Pattern Recognition
- Perception
- Problem Solving
- Projection & Planning
- Situation Awareness

**Physical Behavior (13)**
- Anthropometry
- Biological/Physiological Mechanisms
- Biomechanics
- Endurance & Tolerance
- Fitness & Strength
- Health Protection / Preventive Medicine
- Medical Intervention
- Mobility & Dexterity / Movement
- Nutrition
- Physical Adaptability / Survivability
- Physical Comfort
- Sensing
- Task Execution /Action & Reaction
MANPRINT Domains

1. Manpower
2. Personnel
3. Training
4. Human Factors Engineering
5. System Safety
6. Health Hazards
7. Soldier Survivability

‡ Human Factors Engineering (HFE) Taxonomy adapted from Salvendy (2006)

HFE Taxonomy‡

- Environment
- Information/Communications
- Characteristics/Organization/Design
- Workspace Design
- Methods & Techniques
Current: Warfighter to Human Dimension (and back)

MANPRINT Domains
1. Manpower
2. Personnel
3. Training
4. Human Factors Engineering
5. System Safety
6. Health Hazards
7. Soldier Survivability

System Integration Domains
- LCMCs, PEOPMs
- Force Operating Capabilities
- Warfighter Outcomes

Optional Shortcut

Current ARCIC Function

Warfighting: f(personnel, materiel, mission)

Requirements Flow
Solutions Delivery

Integration Process

S1, S2, . . . , S9
C1, C2, . . . , C12
P1, P2, . . . , P13

Integration of Behaviors, e.g. Imprint

Social
Cognitive
Physical
Current: Warfighter to Human Dimension (and back)

Tri-Service MANPRINT Taxonomy

MANPRINT Domains
1. Manpower
2. Personnel
3. Training
4. Human Factors Engineering
5. System Safety
6. Health Hazards
7. Soldier Survivability

System Integration Domains

Force Operating Capabilities

Warfighter Outcomes

LCMCs, PEOPMs

Current ARCIC Function

Optional Shortcut

Warfighting: f(personnel, materiel, mission)

Requirements Flow

Solutions Delivery

M = Integration Process
Alternate: Warfighter to Human Dimension (and back)

MANPRINT Domains

1. Manpower
2. Personnel
3. Training
4. Human Factors Engineering
5. System Safety
6. Health Hazards
7. Soldier Survivability

System Integration Domains

LCMCs, PEO/PMs

C METLs
D METLs

Warfighting: f(personnel, materiel, mission)

Proposed ARCIC Linkage: Based on the OSD/P&R Assessment Process

M = Integration Process

Optional Shortcut

Requirements Flow
Solutions Delivery
MBT&E Framework – v2

**Process/Products**
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**Capability** = Set of Tasks + Desired Result
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  - Desired System Performance Results

**Essence:**
What must be accomplished and Why

**Implementation:**
DOTMLFP
How and Who

**DOTMPF Component**
Mission-base SE in an SoS Environment enables identification, trade-off, and design of System structure and allocation, characteristics and performance to:

– Prioritize by stressor relevance to End-Results, Mission-Task effectiveness, SoS-Task performance, Human Dimension, and Operational Variables as well as stressor relevance to traditional Materiel and Technology considerations.

– Articulate the impact of System capabilities in the language of the warfighter as expressed in the originating JCIDS FAA, FNA, and FSA

FAA: Functional Area Analysis
FNA: Functional Needs Analysis
FSA: Functional Solution Analysis
Summary

- For identified gaps in required Capability, employ a Mission-Essential-Task-List (METL, with measure, conditions and standards) centric Systems-of-Systems (SoS) approach to complete the (traditional) materiel centric Systems Engineering “V” (SE-V) in the conception, development, evaluation, and fielding of DOTMLPF (Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities) solutions for the warfighter.

- The key is systematically deriving, retaining, and employing Mission, Task, and Human Dimension context throughout the extended SE-V in the SoS environment to need analysis, trade study, design allocation, and capability assessment results in traditional materiel centric terms and their relationships and contributions both direct and indirectly to the impact on warfighting operational performance and mission effectiveness.

- This approach is an application of the Missions and Means Framework (MMF) that is tailored to be compatible with the existing Army Guidance for Employment of Forces (GEF) directive for certifying operational forces prior to deployment, the recently released USD/AT&L Systems Engineering Guide for a SoS Environment, and the emerging ATEC Mission-Base Test & Evaluation (MBT&E) and DOT&E Joint Test & Evaluation Methodology (JTEM) a frameworks and procedures.
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• **System of Systems (SoS)** - is defined as a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities [DoD, 2004(1)].

• Both individual systems and SoS conform to the accepted definition of a system in that each consists of parts, relationships, and a whole that is greater than the sum of the parts; however, although an SoS is a system, not all systems are SoS. *

* Taken from the DoD SE Guide for SoS
• **Virtual SoS** – Group lacks a central management authority and a centrally agreed upon purpose for the system-of-systems.

• **Collaborative SoS** – Group component systems interact more or less voluntarily to fulfill agreed upon central purposes.

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• When a group of systems morphs into an SoS – synergy occurs between the various systems
• When a group of systems is not an SoS – synergy between the various elements does not occur

* Taken from the DoD SE Guide for SoS
Human Factors Engineering Taxonomy

Environment (5)
- Noise
- Vibration
- Climate
- Whole Body Movement
- Fatigue

Info – Commo (5)
- Visual and Auditory Communication
- Media Selection
- Modality Selection
- Decision Making
- Human Robot Interaction

Characteristics / Org. Design (4)
- Individual Differences
- Physiological and Anatomical Aspects
- Group factors
- Job Design

Workspace Design (7)
- Crew Station Design
- Soldier Equipment Design
- Visual Displays
- Auditory Displays
- Tactile/Haptic Displays
- Input Devices & Controls
- State Dependent Design

Methods & Techniques (4)
- Models and Simulations
- Measures
- Analysis Approaches and Methods
- Soldier State Classification
<table>
<thead>
<tr>
<th>Context Dependency</th>
<th>Mission</th>
<th>Doctrine</th>
<th>Organization</th>
<th>Organization Success Measures</th>
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<tbody>
<tr>
<td>Context Dependent</td>
<td>Major Combat Ops</td>
<td>Match</td>
<td>Match</td>
<td>Exist</td>
</tr>
<tr>
<td>Context Dependent</td>
<td>Stability &amp; Support Ops</td>
<td>Mismatch</td>
<td>Mismatch</td>
<td>Not well developed</td>
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<tr>
<td>Context Independent</td>
<td>Maintain Force</td>
<td>Match</td>
<td>Match</td>
<td>Exist</td>
</tr>
<tr>
<td>Context Independent</td>
<td>Establish Cordon</td>
<td>Match</td>
<td>Match</td>
<td>Exist</td>
</tr>
</tbody>
</table>
## SoS Forms Crossed with Acquisition Organizational Processes

<table>
<thead>
<tr>
<th></th>
<th>System</th>
<th>Directed SoS</th>
<th>Acknowledged SoS</th>
<th>Collaborative SoS</th>
<th>Virtual SoS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governance</td>
<td>Feudal</td>
<td>Central with limited local autonomy (France, Russia)</td>
<td>Federation with states rights freedom of action (US, Canada)</td>
<td>Tribal</td>
<td>Fair market economy</td>
</tr>
<tr>
<td>Conflict Resolution</td>
<td>Adjudicated</td>
<td>Adjudicated</td>
<td>Negotiated</td>
<td>Competed</td>
<td>Pair-wise consent</td>
</tr>
<tr>
<td>Schedule</td>
<td>Synchronized</td>
<td>Synchronized</td>
<td>Emergent</td>
<td>Synchronized</td>
<td>Asynchronous</td>
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<td>------------</td>
</tr>
<tr>
<td>Enterprise</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Communities of interest</td>
<td>Yes, A Priori by design, Stable over whole period</td>
<td>Yes, A Priori by design, evolving, stable when eventually complete</td>
<td>Yes, Evolving during development, then stable when complete</td>
<td>Yes, Evolving during development, then stable when complete</td>
<td>Yes, Morphs as the partners change</td>
</tr>
<tr>
<td>local</td>
<td>Yes Abrams</td>
<td>Yes SoSCOE</td>
<td>Yes USMTF/VMF</td>
<td>Yes AKO</td>
<td>Yes Proprietary Protocols</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td><strong>Program Risk</strong></td>
<td>Internal</td>
<td>Internal &amp; external</td>
<td>Internal &amp; external</td>
<td>Internal &amp; external</td>
<td>internal</td>
</tr>
<tr>
<td><strong>AoA – TRADOC</strong></td>
<td>Early, simple, and complete</td>
<td>Extensive and on-going</td>
<td>Extensive and on-going</td>
<td>Extensive at S level but not at SoS level</td>
<td>Partner selection in business sense</td>
</tr>
<tr>
<td><strong>Rqmts - PM</strong></td>
<td>Directed</td>
<td>Directed</td>
<td>Directed</td>
<td>Negotiated</td>
<td>Pair-wise Consent</td>
</tr>
<tr>
<td><strong>Trade Studies - PM</strong></td>
<td>Early, simple, and complete</td>
<td>Extensive and on-going</td>
<td>Extensive and on-going</td>
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</tr>
<tr>
<td><strong>Build - PM</strong></td>
<td>Well defined prime</td>
<td>Multiple primes &amp; PMs</td>
<td>Multiple primes &amp; PMs</td>
<td>Competitive</td>
<td>By independent partners</td>
</tr>
<tr>
<td><strong>Integrate, V&amp;V - PM</strong></td>
<td>Internal to defined prime</td>
<td>Over multiple primes &amp; PMs</td>
<td>Over multiple primes &amp; PMs</td>
<td>Over multiple primes &amp; PMs</td>
<td>Internal to partnership</td>
</tr>
<tr>
<td><strong>T&amp;E - ATEC</strong></td>
<td>Independent oversight</td>
<td>Independent oversight</td>
<td>Independent oversight</td>
<td>By developers</td>
<td>By customers</td>
</tr>
</tbody>
</table>