System of Systems Engineering from a Standards, V-Model, and Dual V-Model Perspective

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Contents

• Introduction
• Systems Engineering Views
• What is Different About SoSE and FoSE?
• Building Block
• V-Model
• Technical Baselines, Documents, and Reviews for a System
• Simple Definitions of SoS and FoS
• INCOSE’s Definitions of System and SoS
• U.S. Department of Defense’s Definitions of SoS and FoS
• V-Model Example for a System of Systems
• Technical Baselines, Documents, and Reviews for a SoS
• Systems Thinking
• Conclusion
• Summary
Introduction

• System of Systems Engineering (SoSE) and Family of Systems Engineering (FoSE) continue to be two of the least well-understood SE disciplines.

• Knowledge of the SE process standards, the V-Model, and particularly the 3-dimensional Dual-V Model, significantly aid this understanding, including the relationship between SE, SoSE, and FoSE.

• The goals of this presentation are to:
  - Define SoS, SoSE, and FoSE from an SE Standards perspective
  - Describe the original V-Model and the Dual-V Model
  - Show how to apply these SE Standards and V-Models to a system, to SoSs, and to FoSs
  - Encourage and challenge the participants to understand, select, tailor, and apply these SE standards and V-Models to complex SoSs and FoSs

• Individuals may have an understanding of portions of SE, SoSE, and FoSE based on other sources. The SE Standards, V-Model, and Dual-V Model provide a more complete and common understanding.
Introduction (cont)

- SoSE versus SE is currently debated in the literature and at conferences such as this.

- Question: Is engineering a SoS really any different from engineering an ordinary system?
  - Some believe SoSE is “different” from SE, the SE processes are inadequate or insufficient for SoSE, and additional processes are needed.
  - Others, like me, believe the SE processes as documented in the SE standards: IEEE 1220, EIA/IS-632, EIA-632, ISO 15288, and the guide: ISO TR 19760, are a necessary and sufficient set of processes for SoSE, and no additional processes are needed. Otherwise, please help us revise these standards.

- In my opinion (based on reading, comparing, understanding, teaching, revising, tailoring, and applying the SE standards):
  - There is only one classical SE process
  - There are multiple views of this one classical process
  - These multiple views provide a comprehensive view as shown in the next chart. By understanding them, you get a comprehensive view.
Multiple views provide a comprehensive view.
What is Different About SoSE and FoSE?

• The management (e.g., acquisition) processes are inadequate, not the technical (SE Standards) processes:
  - There is no god (no overall Program Manager) of a SoS or FoS
  - Acquisitions are stovepipes (single systems, not SoS or FoS)
  - Systems are directed to “integrate” with other systems, often after fielding
  - Suppliers don’t cooperate with each other in FoSE (they believe it’s not in their best interest)
  - Acquirers don’t cooperate with each other for the same reason
  - FoSE costs more up-front to develop for re-use (but saves much more later)
  - Interoperability is hampered by lack of SoSE and FoSE
System Building Block

- System
  - Products
    - Subsystem
  - Processes
    - Subsystem
  - People
V-Model (cont)

System or SoS V-Model


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FoS V-Model

USER REQUIREMENTS, SYSTEM CONCEPT, VALIDATION PLAN

SYSTEM SPECIFICATION AND VERIFICATION PLAN

CONFIGURATION ITEM (C) "DESIGN -TO" SPECIFICATIONS AND VERIFICATION PLAN

"BUILD -TO" SPECIFICATIONS AND VERIFICATION PROCEDURES

FABRICATE, ASSEMBLE, CODE

VALIDATE SYSTEM TO USER REQUIREMENTS

INTEGRATE SYSTEM AND VERIFY TO SPECIFICATIONS

ASSEMBLE CIS AND VERIFY TO SPECIFICATIONS

INSPECT/TEST TO "BUILD -TO" SPECIFICATIONS

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Dual V-Model Example

- System V-Model
- 1 System
- 2 Subsystems
- Entity V-Models
- 4 Lowest Configuration Items

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V-Model (cont)

Dual V-Model Example Details (1 System V)

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Dual V-Model Example Details (1 System Entity V)
Dual V-Model Example Details (2 Subsystem Entity Vs)

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Dual V-Model Example Details (4 Lowest Configuration Item Entity Vs)

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Dual V-Model Example Sequence

1 System
2 Subsystems
4 Lowest Configuration Items

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# Technical Baselines, Documents, and Reviews for a System

**FULL MENU**

<table>
<thead>
<tr>
<th>Review Types:</th>
<th>System Requirements Baseline</th>
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<tbody>
<tr>
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<table>
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<tr>
<th>Document Types:</th>
<th>System Allocated Baseline = Subsystem Requirements Baseline</th>
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**SYSTEM LEVEL**

- System requirements allocated to subsystems

**SUBSYSTEM LEVEL**

- Subsystem requirements allocated to Lowest Configuration Item (LCI)

**LOWEST CONFIGURATION ITEM (LCI) LEVEL**

- Subsystem Allocated Baseline = LCI Requirements Baseline (e.g., Software CI Requirements Baseline)

**Diagram**

- **SYSTEM LEVEL**
  - System Requirements Baseline
  - System requirements allocated to subsystems

- **SUBSYSTEM LEVEL**
  - Subsystem Allocated Baseline = Subsystem Requirements Baseline
  - Subsystem requirements allocated to Lowest Configuration Item (LCI)

- **LOWEST CONFIGURATION ITEM (LCI) LEVEL**
  - Subsystem Allocated Baseline = LCI Requirements Baseline (e.g., Software CI Requirements Baseline)

**Rollup:**

- Subsystem 
- Subsystem requirements 
- Lowest Configuration Item (LCI)

**Roll-down:**

- System Requirements Baseline 
- System requirements 
- Subsystem Requirements Baseline 
- Subsystem requirements 
- LCI Requirements Baseline 

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Simple Definitions of SoS and FoS

- **SoS**: The sum of the whole is **greater** than the sum of the individual parts
  - The parts are integrated (i.e., have interfaces)
  - The parts may or may not be members of a common domain (such as a product line, for example: surface ship radars)

- **FoS**: The sum of the whole is **equal** to the sum of the individual parts
  - The parts are not integrated
  - The parts are members of a common domain (such as a product line)
Defense Acquisition Guidebook (DAG)-2006 Definition of SoSE

• Deals with planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a SoS capability greater than the sum of the capabilities of the constituent parts.

• SoSs should be treated and managed as a system in their own right, and should therefore be subject to the same systems engineering processes and best practices as applied to individual systems.

• Differs from the engineering of a single system. The considerations should include the following factors or attributes:
  • Larger scope and greater complexity of integration efforts;
  • Collaborative and dynamic engineering;
  • Engineering under the condition of uncertainty;
  • Emphasis on design optimization;
  • Continuing architectural reconfiguration;
  • Simultaneous modeling and simulation of emergent System of Systems behavior; and
  • Rigorous interface design and management.
U.S. Department of Defense’s Definitions of SoS (cont)


• A SoS is a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities.

• 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.

• Consistent with the DoD transformation vision and enabling net-centric operations (NCO), SoS may deliver capabilities by combining multiple collaborative and autonomous-yet-interacting systems.

• The mix of systems may include existing, partially developed, and yet-to-be-designed independent systems.

- The SE Guide to SoS identifies 3 new SoS SE “roles”:
  - Translating Capability Objectives
  - Understanding Systems & Relationships
  - Monitoring & Assessing Changes

- It is unclear to me why these three SoS SE roles are really “new.” In my opinion they are included in the 16 technical and technical management processes defined in the DAG chapter 4, and are included in the SE Standards, V-Model, and Dual-V Model on which the DAG chapter 4 is based.
 Joint Capabilities Integration and Development System (JCIDS)  
Definition of SoS

• A set or arrangement of interdependent systems that are related or connected to provide a given capability. The loss of any part of the system will significantly degrade the performance or capabilities of the whole.

• The development of a SoS solution will involve trade space between the systems as well as within an individual system performance.

• An example of a SoS would be a combat aircraft. While the aircraft may be developed as a single system, it could incorporate subsystems developed for other aircraft. For example, the radar from an existing aircraft may be incorporated into the one being developed rather than developing a new radar. The SoS in this case would be the airframe, engines, radar, avionics, etc. that make up the entire combat aircraft capability.
U.S. Department of Defense’s Definitions of FoS

Defense Acquisition Guidebook (DAG)-2006 Definition of FoS

- Is not considered to be a system per se.
- Does not create capability beyond the additive sum of the individual capabilities of its member systems.
- Basically a grouping of systems having some common characteristic(s). For example, each system in a FoS may belong to a domain or product lines (e.g., a family of missiles or aircraft).
- Lacks the synergy of a SoS.
- Does not acquire qualitatively new properties as a result of the grouping. In fact, the member systems may not be connected into a whole.
U.S. Department of Defense’s Definitions of FoS


• A set of systems that provide similar capabilities through different approaches to achieve similar or complementary effects.

• For instance, the war fighter may need the capability to track moving targets. The FoS that provides this capability could include unmanned or manned aerial vehicles with appropriate sensors, a space-based sensor platform, or a special operations capability. Each can provide the ability to track moving targets but with differing characteristics of persistence, accuracy, timeliness, etc.
INCOSE’s Definitions of System and SoS

• A system is a combination of interacting elements organized to achieve one or more stated purposes.

• System of systems applies to a system-of-interest whose system elements are themselves systems; typically these entail large scale inter-disciplinary problems with multiple, heterogeneous, distributed systems.

Further simplification by myself leads to:

• System of systems applies to a system whose system elements are themselves systems.
V-Model Example for a System of Systems

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## Technical Baselines, Documents, and Reviews for a SoS

### Review Types:
- A (Review)  
- R (Review)  
- F (Fame)  
- PD (Plan)  
- I (Inform)  
- CD (Checklist)  
- TR (Test)  
- TC (Test)  
- FCA (Function Check and Analysis)  
- VR (Verification and Validation)  
- PCA (Performance Check and Analysis)

### Document Types:
- SoS  
- SoS Requirements  
- ORD/ICD  
- S/SS  
- IRS  
- SDD  
- HDD  
- IDD  
- DBDD  
- SDD  
- HDD  
- IDD  
- DBDD  
- T Plan  
- T Proc  
- T Rpt  
- Rpt  
- Rpt  
- Rpt

### SoS Level Requirements Baseline

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<th>SoSFR</th>
<th>SoSPDR</th>
<th>ISoSR</th>
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### System Level Requirements Baseline

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<th>SoSDD</th>
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### System Allocated Baseline

SoS Allocated Baseline = System Requirements Baseline

Rqmts flow down:
- SRR  
- SFR  
- SPDR  
- ISR  

Roll up:
- SCDR  
- STRR  
- STCR  
- SFCA  
- SPCA

### Subsystem Level Requirements Baseline

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<th>SubRR</th>
<th>SubFR</th>
<th>SubPDR</th>
<th>SubCDR</th>
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### System Allocated Baseline

System Allocated Baseline = Subsystem Requirements Baseline

Rqmts flow down:
- SubRS  
- SubRS  
- SubDD  
- SubDD  
- SubDD  
- SubDD  
- SubDD  

Roll up:
- SubT Plan  
- SubT Rpt  
- SubT Proc  
- SubT Proc  
- SubT Proc  
- SubT Proc  
- SubT Proc

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Systems Thinking

• Everything and everyone (from the universe to the nucleus of an atom) is a system, a SoS, and a subsystem of a higher-order system

• Everything and everyone that exists/existed (things, people, thoughts, sayings, writings, actions, etc.) uses/used the systems engineering process

• You see everything and everyone as a system, a SoS, a subsystem of a higher-order system, and a member of a FoS

• You “Stand on the standards”

• You have “The Knack”
Conclusion

• Is engineering a SoS really any different from engineering an ordinary system?

• Some believe that SoSE is “different” from SE, the SE processes are inadequate or insufficient for SoSE, and additional processes are needed.

• Others, like me, believe the SE processes as documented in the SE process standards, and as illustrated in the V-Model and Dual-V Model, are a necessary and sufficient set of processes for SoSE, and no additional processes are needed. If you disagree, please get involved in the SE standards working groups and help us fix them.
Summary

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THE END!

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BACKUP

Not in the Paper
Hypotheses, Challenges, and Objectives

• Hypotheses:
  - The SE Standards and V-Models describe the SE processes very well.
  - The SE Standards and V-Models contain a necessary and sufficient set of SE processes for solving complex SE and SoSE/FoSE problems.
  - Apply the SE Standards and V-Model processes that we already have to these problems, they will work.
  - The technical (SE Standards and V-Model) processes are adequate, the management (e.g., DoD acquisition) processes are not

• Challenges:
  - Communicate what the SE Standards and V-Models say about the SE processes for solving complex SE and SoSE/FoSE problems.
  - Gain consensus on what the SE Standards and V-Models say.
  - Convince stakeholders to read, understand, tailor, and apply the SE Standards and V-Models to solve these problems.
  - Obtain help to correct the SE Standards and V-Models if they’re inadequate.

• Objectives:
  - Describe SE, SoSE, and FoSE from the SE Standards and V-Models perspective / view (EIA/IS-632, IEEE 1220, EIA-632, ISO 15288, Dr Kevin Forsberg)
  - Demonstrate that these SE standards and V-Models contain a complete set of SE processes for complex SE and SoSE/FoSE problems, and no additional processes are necessary
  - Show how to apply these SE standards and V-Models
  - Promote “Systems Thinking”