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Identifying Hidden Requirements in System of Systems

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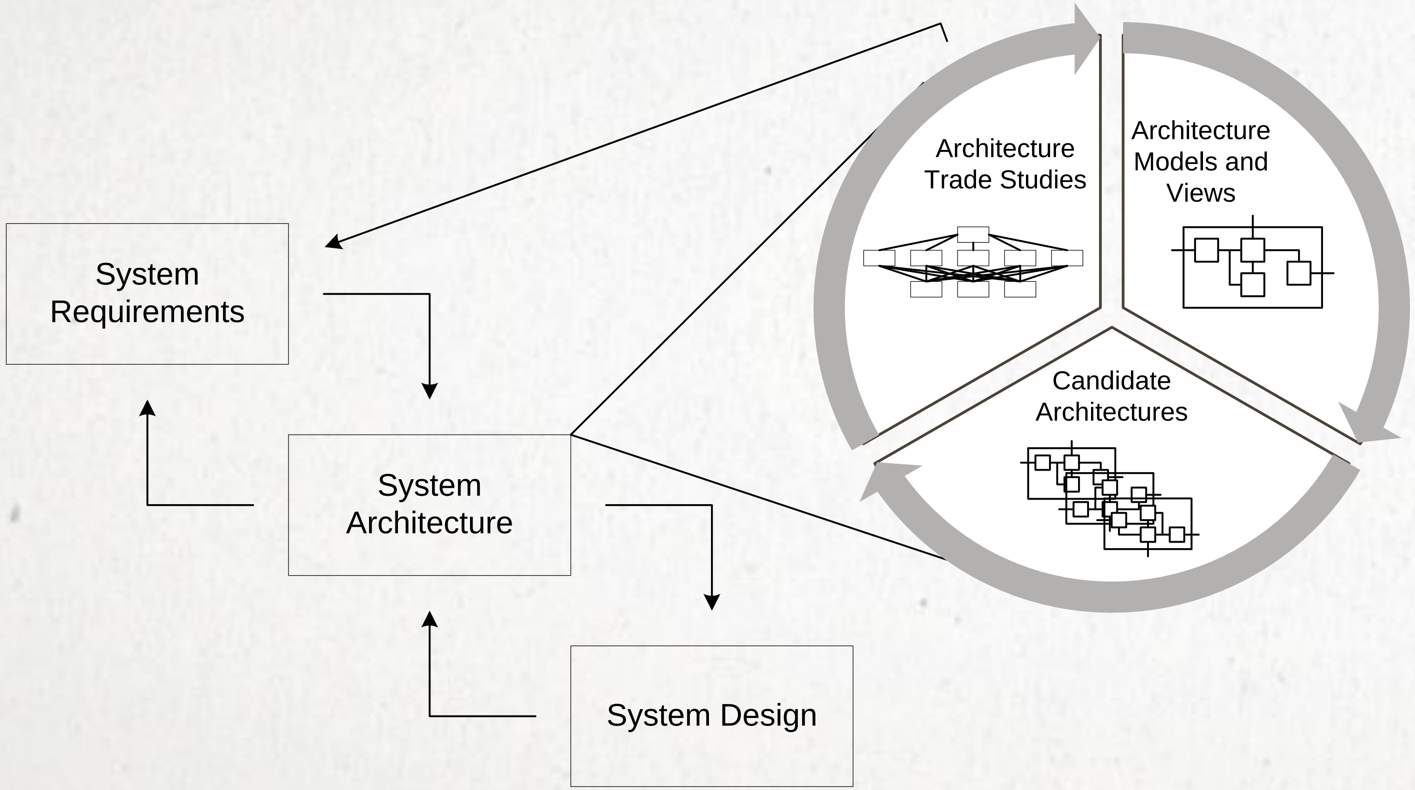
SUMMARY

- System of Systems (SoS) Architecture Synthesis Process Naturally Exposes Hidden or Derived Requirements
- Include Early Architecture High Level Views as Part of SoS Concept System Selection Trade Space
- Expert Judgment Vital for SoS Concept Selection Analysis of Alternatives (AOA)
- Paired Comparison Methods Ideal for AOA in SoS Concept System Selection
- Paired Comparison AOA Example

SIMPLE SOS ARCHITECTURE SYNTHESIS CYCLE



Synthesis Process and Outcomes

- Develop high level SoS architecture alternatives
- Uncover SoS hidden requirements
- Update candidate architectures to address the uncovered requirements
- For SOS this process continues throughout the life cycle
- Include candidate architectural views for early concept trade space inclusion

In practice SoS architectural synthesis is an evolutionary process

WHY EXPERT JUDGMENT IS VITAL DURING SOS CONCEPT PHASE?

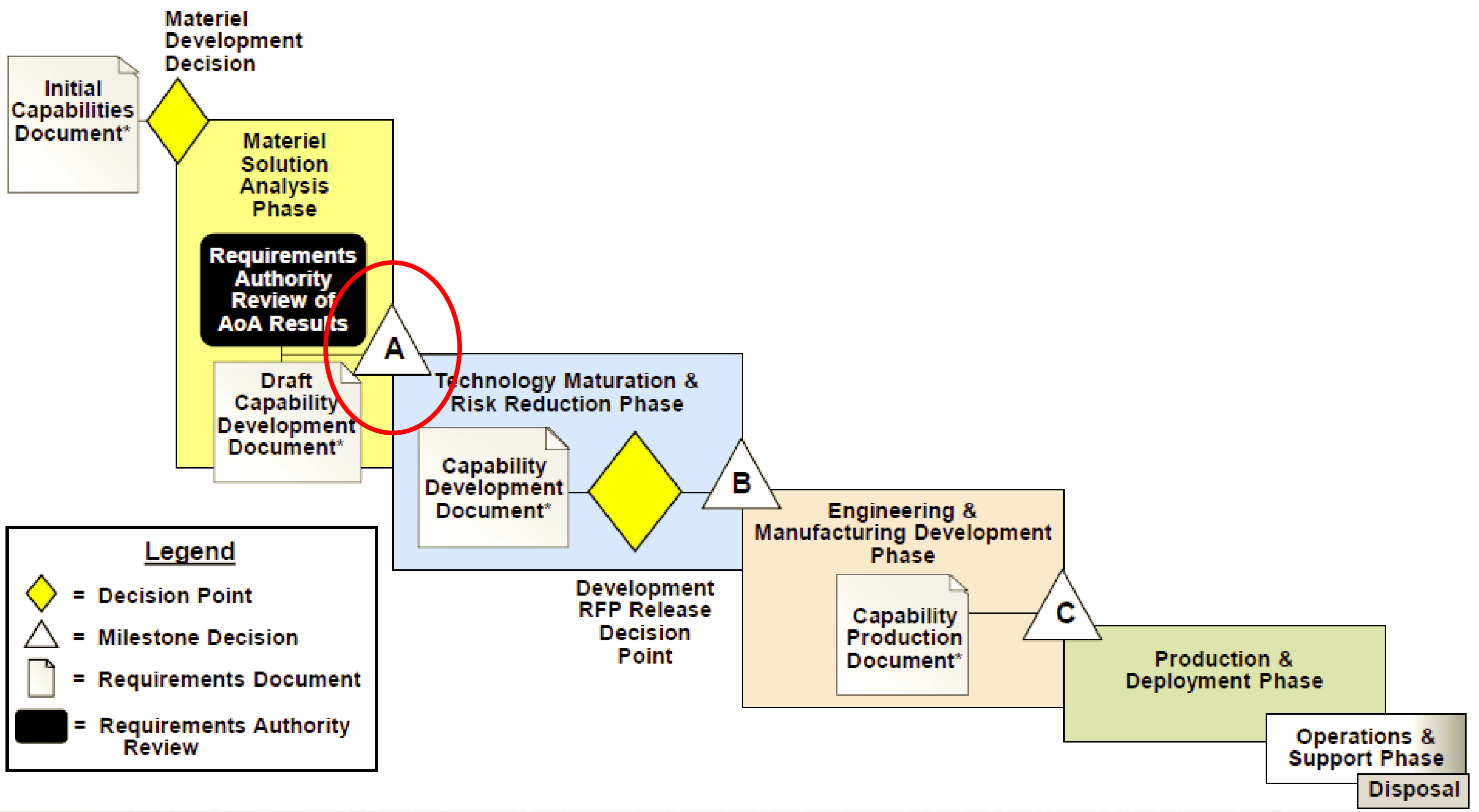


Figure from DoDI 5000.02

- Early program decisions have huge life cycle cost implications
- Constituent system perspectives - experts hold unique sets of domain expertise
- SMEs can communicate tacit and lessons learned knowledge
- SME domain support is critical for decision gates such as U.S DoD Milestone A decision.

For U.S. DoD AoA is mandatory for major material development programs to support milestone A decision

SOS CONCEPT SYSTEM SELECTION AOA TRADE SPACE

- Key Early Architectural Views
- Cost & Schedule Estimates
- Capability Objectives
- Affordability
- Risk (TRL)

DoDI 5000.02 recommends AOA trade space includes estimates for cost, schedule, key capability performance, affordability and risk.

WHY EXPERT JUDGMENT FOR SOS AOA

- **Expert Elicitation** is Crucial in Reducing SoS Undesirable Emergent Behavior Which Increases Program Technical, Cost and Schedule Risk. *(modified from INCOSE HB v4.0 page 12)*
- Interaction Amongst SMEs can Uncover Constituent Systems Undocumented Features, Constraints and Assumptions

WHY PAIRED COMPARISON METHODOLOGY FOR SOS AOA?

- Mythology was Developed to Elicit Expert Judgment for Decision Analysis
- Favorable Methodology for Relative Assessments
- Paired Comparison Methodology is Ideal for Contextual Trade Space
  - Such as Affordability, Cost-Effective Capability and Risk
- Enables Judge or Respondents Reliability Checking
- Models are Available to Support Hypothesis Testing

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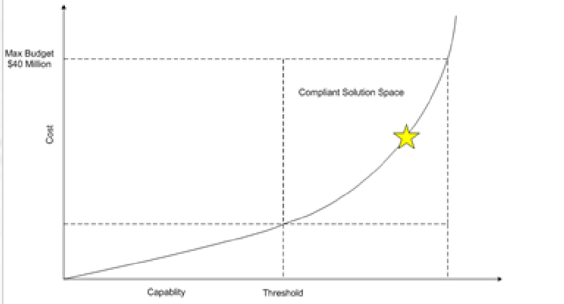
PAIRED COMPARISON AOA EXAMPLE

- In this example there are two platforms, two radar systems and two EO/IR SoS candidate architectures for comparison
- Populate paired scoring sheets for each SoS concept candidate (6 in this example)
- Respondents select system preference for each pair of candidate concept solutions (15 paired comparisons in this example)
- Configure aggregate preference matrix
- Verify respondent consistency and reliability learned from the data
- Use models for hypothesis testing

Example Data for Academic Purposes Only

Candidate System 1
(Platform 1, Radar 1, EO/IR 1)

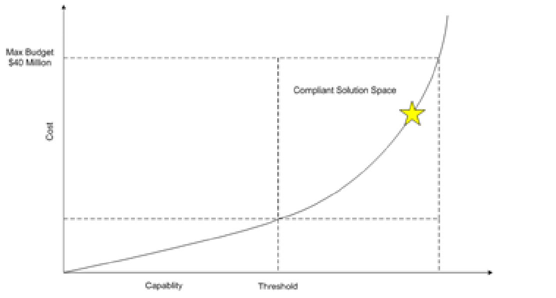
Architecture	
See OV1, SV1, SV6 & IBD	
Affordability	
Platform Cost	8.2 million
GMTI/SAR Acquisition Cost	2.2 million
EO/IR Acquisition Cost	0.8 million
Workstation & Network Cost	1.1 million
20 yr. LC Support Cost	22 million



Schedule	
Integrated and Contractor Tested	16 mo. ARO
Risk (TRL)	
Platform 1	9
Radar 1	7
EO/IR	9
Key Capabilities	
Platform 1	
Platform 1 Time on Station	6 hrs.
Platform 1 Payload Capacity	5200 lbs.
Platform 1 Payload Max Pwr	10 KVA
Number of Workstations	2
GMTI/SAR 1	
Size	370mm x 470 mm
Weight	30 kg
Power (28 VDC)	600 Watts
Scan Coverage	0 deg az, +10/-55 deg el
Maximum Range	20km
Resolution	< 1 meter
SAR Resolution	3m to <30cm
EO/IR 1	
Size	16" x 19" Turret
Weight	90 lbs.
Power (28 VDC)	300W typ-900W Max
EO/IR Turret FOV	360 az, 90-120 el
EO Resolution / FOV	500 TVL / 1.5 - 20 deg
IR Resolution / FOV	512 x 480 / 25 deg max

Candidate System 2
(Platform 1, Radar 1, EO/IR 2)

Architecture	
See OV1, SV1, SV6 & IBD	
Affordability	
Platform Cost	8.2 million
GMTI/SAR Acquisition Cost	2.2 million
EO/IR Acquisition Cost	1.4 million
Workstation & Network Cost	1.2 million
20 yr. LC Support Cost	24 million



Schedule	
Integrated and Contractor Tested	16 mo. ARO
Risk (TRL)	
Platform 1	9
Radar 1	7
EO/IR	6
Key Capabilities	
Platform 1	
Platform 1 Time on Station	6 hrs.
Platform 1 Payload Capacity	5200 lbs.
Platform 1 Payload Max Pwr	10 KVA
Number of Workstations	2
GMTI/SAR 1	
Size	370mm x 470 mm
Weight	30 kg
Power (28 VDC)	600 Watts
Scan Coverage	0 deg az, +10/-55 deg el
Maximum Range	20km
Resolution	< 1 meter
SAR Resolution	3m to <30cm
EO/IR 2	
Size	18" x 20" Turret
Weight	90 lbs.
Power (28 VDC)	500W typ-1.1KW Max
EO/IR FOV	360 az, 0-55 el
EO Resolution	625 TVL / 1.0 - 28 deg
IR Resolution	640 x 512 / 25 deg max

SIMPLE PAIRED COMPARISON DECISION EXAMPLE

Let there be 20 respondents and one score sheet for each

	1	2	3	4	5	6
1	-	0	0	1	1	1
2	1	-	1	1	1	1
3	1	0	-	1	1	1
4	0	0	0	-	0	0
5	0	0	0	1	-	0
6	0	0	0	1	1	-
Σ	2	0	1	5	4	3

Respondent aggregate score matrix

	1	2	3	4	5	6
1	-	0	0	18	20	20
2	20	-	20	20	20	20
3	20	0	-	18	14	18
4	2	0	2	-	2	4
5	0	0	6	18	-	2
6	0	0	2	16	18	-
Σ	42	0	30	90	74	64
mean	2.1	0	1.5	4.5	3.7	3.2
proportion	0.42	0	0.3	0.9	0.74	0.64

Column-wise aggregate shows candidate system solution 4 is most preferred

Mean = Sum/20 judges
Proportion = Sum/20*(#items-1)

PAIRED COMPARISON MODELS

Respondent Data

- Consistency – consistence with expected values
  - A measure of constancy with the law of comparative judgment
- Reliability – test for circular triads
  - Since paired comparisons are IID some amount of circular triads are acceptable
- Retest Reliability
  - Repeat a small number of paired comparisons and evaluate any inconsistencies

SoS Candidate Data

- Preference Significance – test for preference
  - Is the preferred candidate statistically significant?
- Goodness of fit – chi square distribution of candidate least squared error

QUESTIONS?

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