PURDUE
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Optimal Selection of Organizational Structuring for Complex Systems Development and Acquisitions

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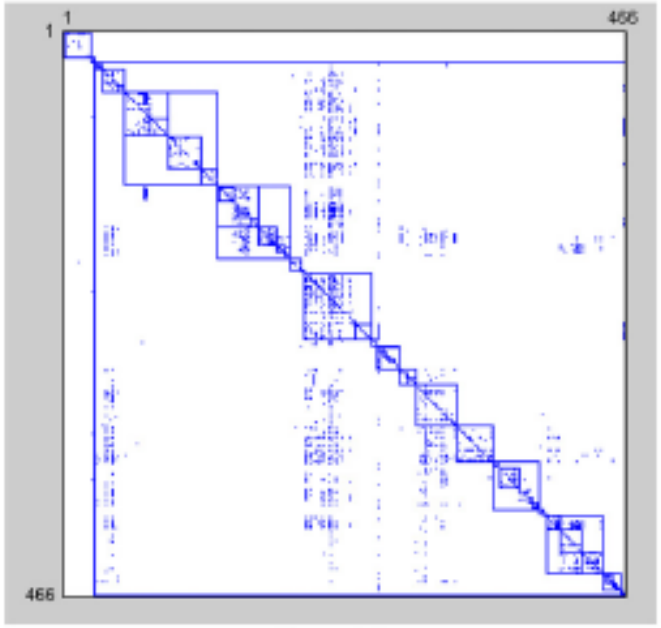
Motivation for Research

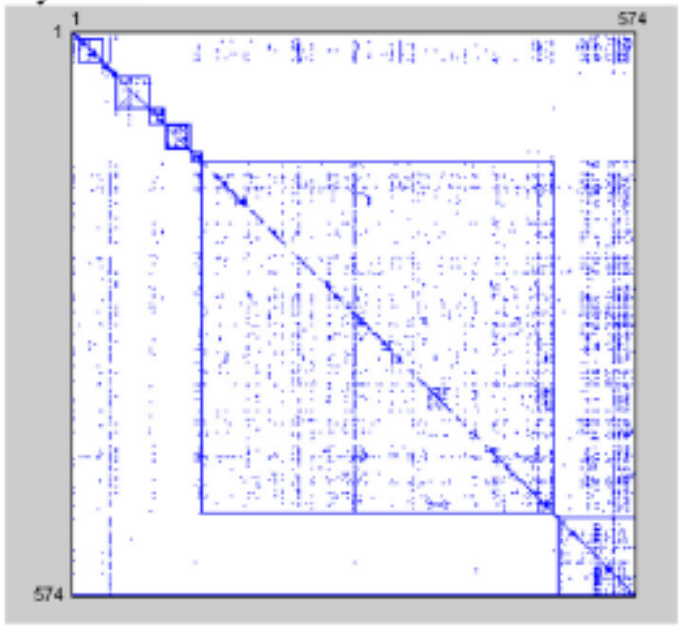
Conway's Law – *"The product architecture tends to mirror the organizational architecture from which they are developed."*

Gnucash 1.8.4



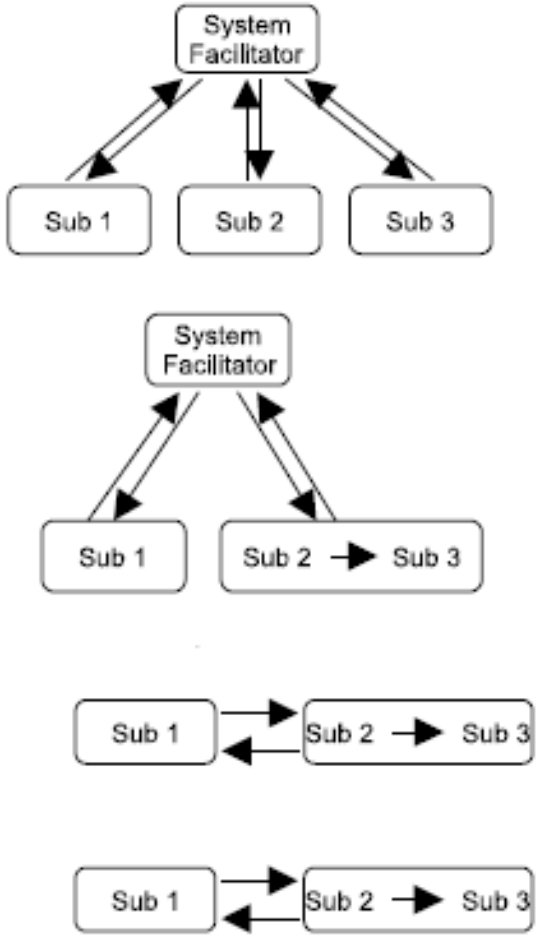
Size = 466
Dependency Density = 1.3672%
Propagation Cost = 7.7428%

MyBooks



Size = 574
Dependency Density = 1.8903%
Propagation Cost = 47.1394%

MacCormack (2007)

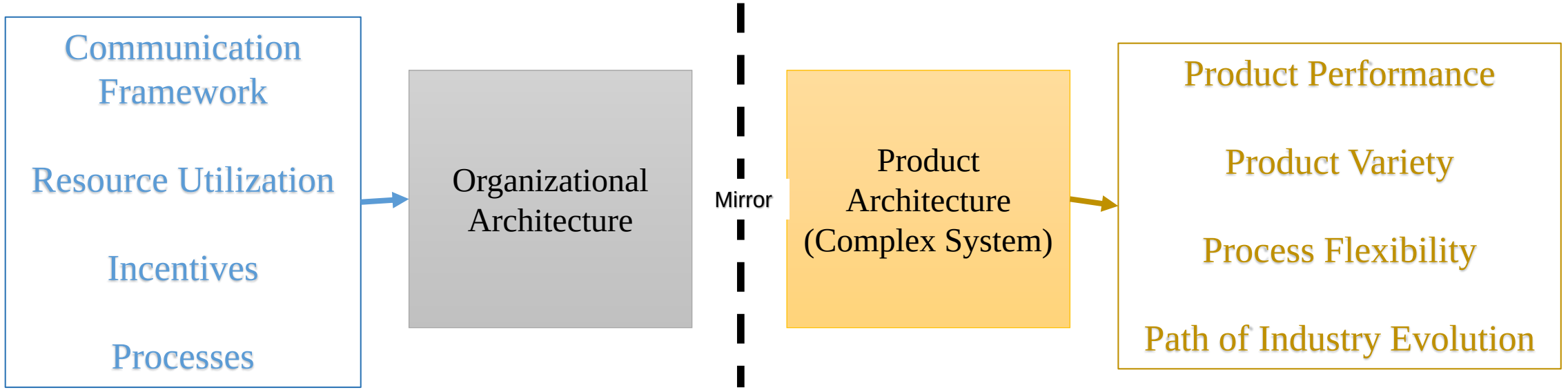


Honda (2015)

References: Honda (2015), MacCormack (2007)

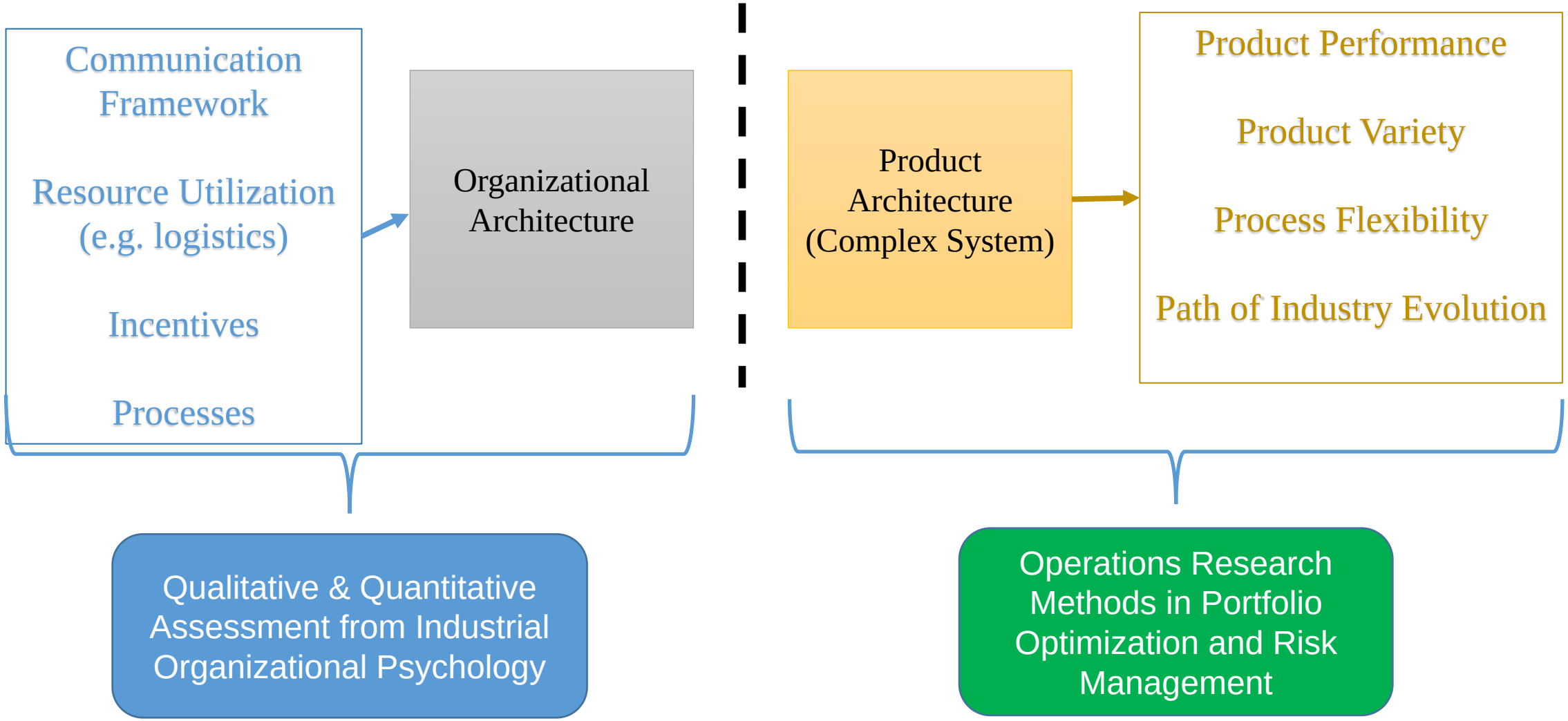
Research Question:

How do we optimally select the organization structure and product structure (complex system structure)?



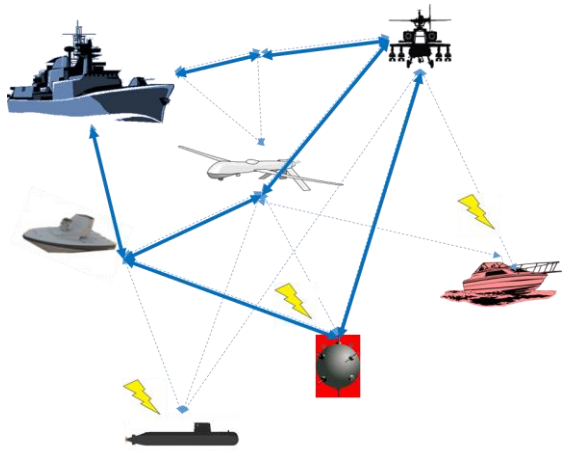
"…there is little quantitative support to assist decision-makers in forming organizational structures that best fits the desired complex systems development and vice versa." – DeLaurentis, 2015

Methodology: A Combined Approach



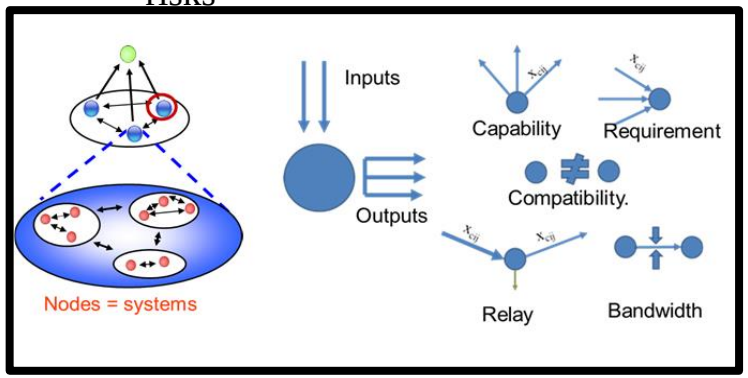
Concept Problem : Complex System Design and Program Manager Allocations

Product Architecture – Complex System Design



Complex System Model:

- Hierarchical abstraction of systems to form architecture
- Systems modeled as ‘nodes’
- Connectivity and resource flow constraints between nodes
- Treat as a portfolio optimization problem of maximizing performance index subject to risks



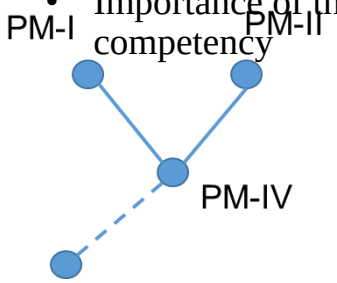
Organizational Architecture

Program Manager Allocation to develop systems based on competency data

Organizational Model

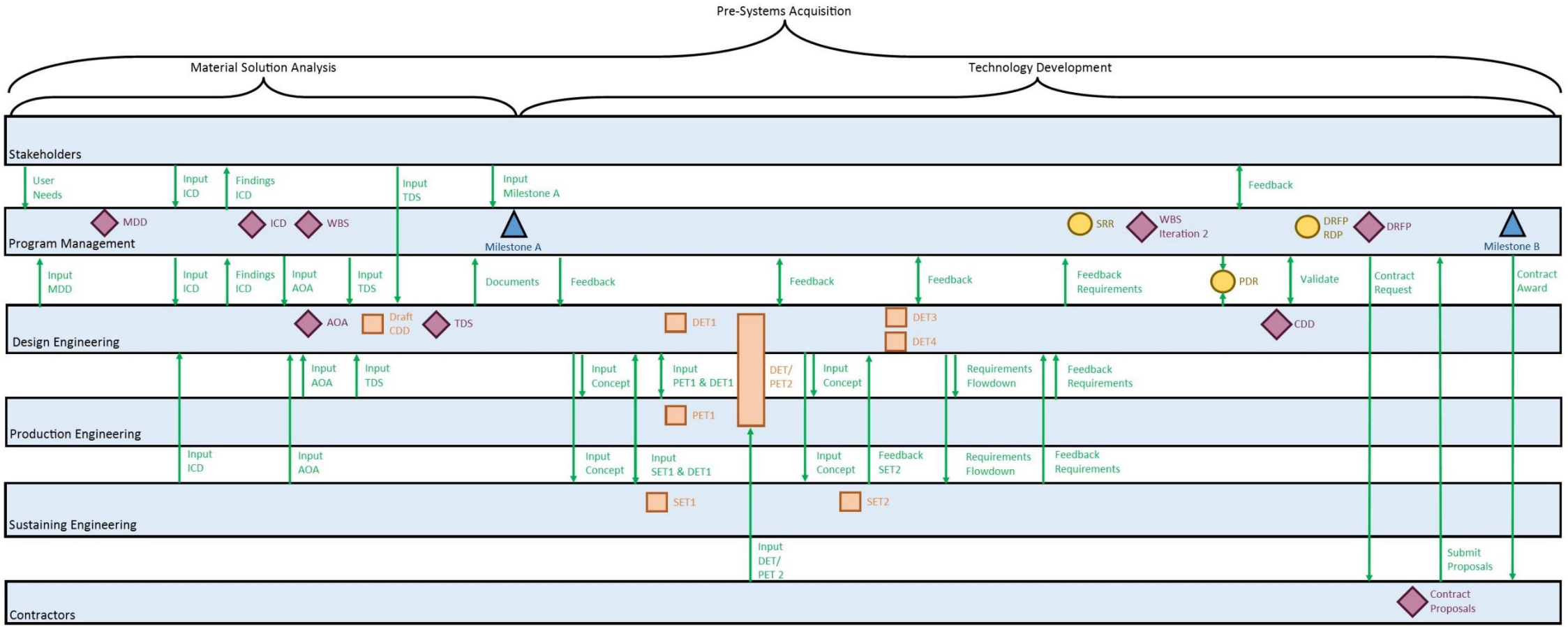
Inspired by:

- **Roy Wood (2010) survey** of 146 DoD program managers by their industry counterparts
  - 35 “hard” and “soft” competencies evaluated on:
    - Performance in the competency
    - Importance of the competency



References: Wood (2010)

DoD Acquisition Life Cycle



Task Descriptions: DET1 – Evaluate program integration and potential risks based on Milestone A results; PET1 – Evaluate potential production needs based on Milestone A results; SET1 – Evaluate potential support and maintenance needs based on Milestone A results; DET/PET2 – Perform competitive prototyping; SET2 – Define support objectives based on competitive prototyping results; DET3 – Develop system architecture; DET4 – Develop technical architecture

References: Department of Defense (2015); Defense Acquisition University (2009)

Organizational Model: Competency Grouping

The Great Eight

Leading & Deciding
Document program assumptions, Project leadership, …

Supporting & Cooperating
Trustworthiness, Issue and conflict resolution, …

Interacting & Presenting
Communicate program status, Negotiations, …

Analyzing & Interpreting
Document program constraints, Measure program performance, …

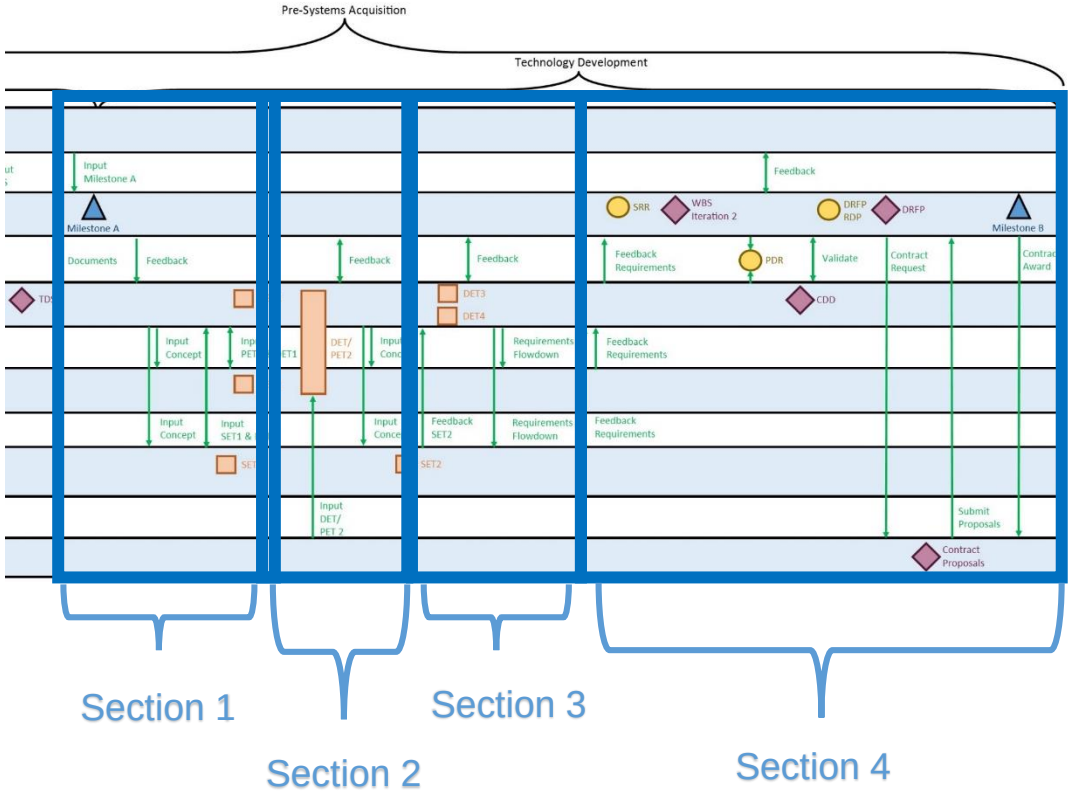
Creating & Conceptualizing
Define program strategy, Decision making, …

Organizing & Executing
Determine program goals, Quality assurance, …

Adapting & Coping
Respond to risk, Flexibility, …

Enterprising & Performing
Technical ability, Sound business judgement, …

Organizational Model : Competency Mapping



Section No.	Lifecycle Span
1	Milestone A – Start of DET/PET 2 (Prototyping)
2	DET/PET 2 – Start of DET 3 (Develop System Architecture) & DET 4 (Develop Technical Architecture)
3	DET 3 & DET 4 – Start of SRR (System Requirements Review)
4	SRR – Milestone B

Organizational Model : Competency Mapping

Great Eight Competencies	Roy Wood Competencies
Leading and Deciding	Document program assumptions; Implement corrective action; Project leadership; Facilitation
Supporting and Cooperating	Trustworthiness; Issue and conflict resolution; Coaching
Interacting and Presenting	Communicated program status; Negotiations; Setting and managing expectations; Communication style; Listening skills; Team building
Analyzing and Interpreting	Document program constraints; Measure program performance; Implement change control; Conduct administrative closure; Problem solving
Creating and Conceptualizing	Define program strategy; Decision making
Organizing and Executing	Determine program goals; Determine program deliverables; Quality assurance; Identify resources requirements; Develop a budget; Create a work breakdown structure (WBS); Develop a resource management plan; Establish program controls; Develop program plan; Organizational Skills
Adapting and Coping	Respond to risk; Flexibility
Enterprising and Performing	Technical ability; Sound business judgement

Organizational Model : Competency Mapping

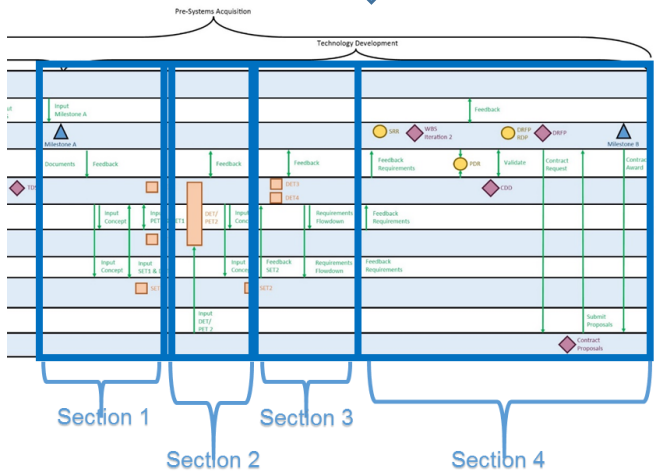
	Acquisition Lifecycle Phase			
	Section 1 – Post A Concept Dev	Section 2 - Prototyping	Section 3 – Req. Dev.	Section 4 – SRR to DRFP
Leading & Deciding	8.0	7.5	9.5	3
Supporting & Cooperating	4.5	6.5	6.5	6.5
Interacting & Presenting	9.0	9	5.5	10
Analyzing & Interpreting	2.5	5	3.5	4
Creating & Conceptualizing	2.0	8	8	6.5
Organizing & Executing	2.0	4.5	3	7.5
Adapting & Coping	2.0	4.5	2	5
Enterprising & Performing	7.0	7	8	7.5

Qualitative analysis of lifecycle section using DoD and GAO documentation

Generate qualitative understanding of necessary program skill for lifecycle section

Assign numeric rating to The Great Eight competencies for lifecycle section

GAO-04-635T Future Combat Systems	GAO-06-110 Better Support of Weapon System Program Managers Needed to Improve Outcomes	GAO-16-489T F-35 Joint Strike Fighter
GAO-14-77 Cancelled DoD Programs: DOD Needs to Better Use Available Guidance and Manage Reusable Assets	GAO-08-674T Defense Acquisitions Results of Annual Assessment of DoD Weapons Programs (Average program delay of 21 months)	GAO-12-400SP Assessments of Selected Weapons Programs



Competency Mapping to Great Eight

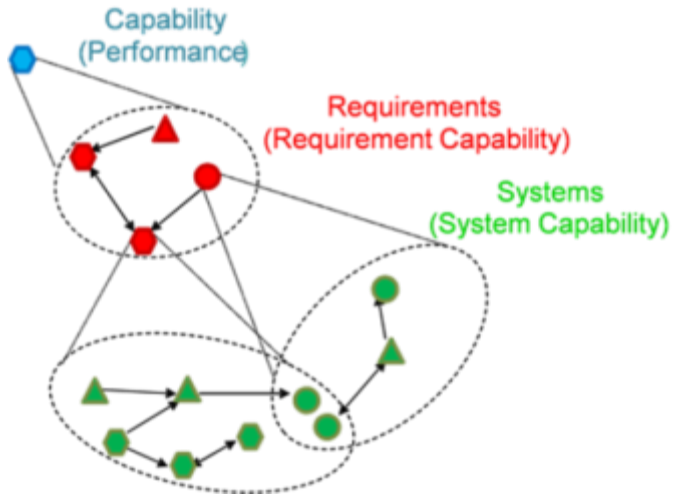
	Acquisition Lifecycle Phase				Program Manager Archetypes (Notional)			
	Section 1 – Post A Concept Dev	Section 2 - Prototyping	Section 3 – Req. Dev.	Section 4 – SRR to DRFP	PM Type I	PM Type II	PM Type III	PM Type IV
Leading & Deciding	8.0	7.5	9.5	3	9	7	6	6
Supporting & Cooperating	4.5	6.5	6.5	6.5	9	6	7	3
Interacting & Presenting	9.0	9	5.5	10	7	5	4	3
Analyzing & Interpreting	2.5	5	3.5	4	5	6	3	3
Creating & Conceptualizing	2.0	8	8	6.5	5	9	9	2
Organizing & Executing	2.0	4.5	3	7.5	6	9	9	1
Adapting & Coping	2.0	4.5	2	5	3	5	5	4
Enterprising & Performing	7.0	7	8	7.5	5	5	7	3

Calculated average risk based on difference between PM and average desired value at each phase

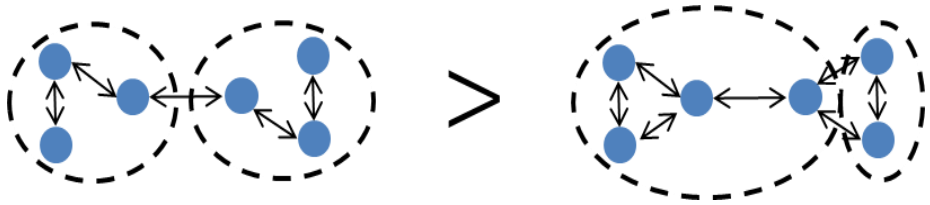
PM Type	Population	Average Risk
I	2	4.1
II	2	5.3
III	2	4.7
IV	2	10.1

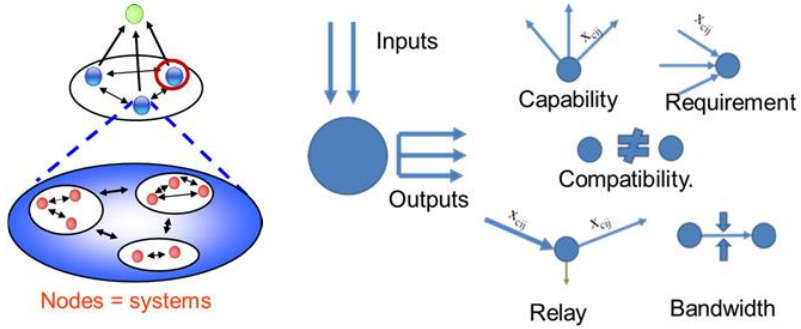
Complex System Architecture Model

		SoS Capabilities (Outputs)			Capabilities (Outputs)				Cost	Num Power	Num Comm	TRL
No.	System Name	SoS CAP 1	SoS CAP 2	SoS CAP 3	Power.	Comm.	Power Req.	Comm Req.	[$]	Links	Links	
1	Control Station 1	150	0	0	150	0	0	0	$10,000.00	3	3	9
2	Control Station 2	300	0	0	300	0	0	0	$20,000.00	3	3	9
3	Control Station 3	450	0	0	450	0	0	0	$300,000.00	3	3	9
4	Control Station 4	600	0	0	600	0	0	0	$400,000.00	3	3	6
5	Control Station 5	750	0	0	750	0	0	0	$500,000.00	3	3	4
6	First Satellite 1	0	0	100	0	0	75	95	$500,000.00	3	3	9
7	First Satellite 2	0	0	200	0	0	125	150	$650,000.00	3	3	9
8	First Satellite 3	0	0	300	0	0	150	250	$750,000.00	3	3	7
9	First Satellite 4	0	0	400	0	0	175	350	$850,000.00	3	3	5
10	First Satellite 5	0	0	500	0	0	185	450	$900,000.00	3	3	4
11	UAV-1	20	0	0	0	0	100	0	$200,000.00	3	3	9
12	UAV-2	30	0	0	0	0	200	0	$300,000.00	3	3	9
13	UAV-3	40	0	0	0	0	300	0	$400,000.00	3	3	4
14	UAV-4	50	0	0	0	0	120	0	$450,000.00	3	3	3
15	UAV-5	60	0	0	0	0	300	0	$500,000.00	3	3	2
16	Carrier Ship -1	0	5	0	0	0	50	0	$500,000.00	3	3	9
17	Carrier Ship -2	0	10	0	0	0	150	0	$600,000.00	3	3	9
18	Carrier Ship -3	0	20	0	0	0	200	0	$700,000.00	3	3	2
19	Second Satellite 1	0	0	100	0	100	0	0	$50,000.00	3	3	9
20	Second Satellite 2	0	0	200	0	200	0	0	$60,000.00	3	3	9
21	Second Satellite 3	0	0	300	0	300	0	0	$70,000.00	3	3	7
22	Second Satellite 4	0	0	400	0	400	0	0	$80,000.00	3	3	3
23	Second Satellite 5	0	0	500	0	500	0	0	$90,000.00	3	3	3



Depending on type/TRL of system, requirement on PM type changes





A Combined Optimization Approach

Objective: Maximize Performance Index

$$\max\left(\sum_q \left(\frac{S_{qc} - R_c}{R_c} \cdot w \cdot X_q^B\right)\right)$$

s.t.

Constraints

Product Architecture Relevant

- Portfolio Total Budget
- Connectivity Rules for Candidate Systems
- Network Resource Flow Balance

$$\sum_i x_{cij} \geq x_j^B S_{rj}$$

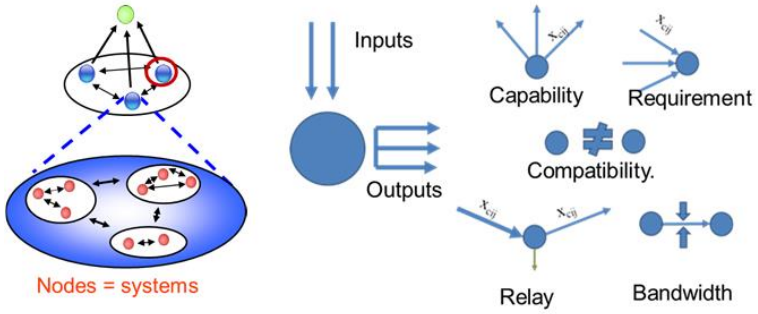
$$\sum_j x_{cij} \leq x_i^B C_{ci}$$

$$x_1^B + \cdots + x_n^B = T$$

$$\sum_c x_{cij} - x^{c_{bin}}_{ij} M \leq 0$$

$$M \sum_c x_{cij} - x^{c_{bin}}_{ij} \geq 0$$

$$\sum_i x^{c_{bin}}_{ij} \leq n_{\max}$$



Organizational Relevant

- Conditional rules based on system selection
- PM allocation limits (population)
- Limit PM average risk

$$\sum_i x_{cij} - \sum_j x_{cij} - x_j^B S_{rj} = 0$$

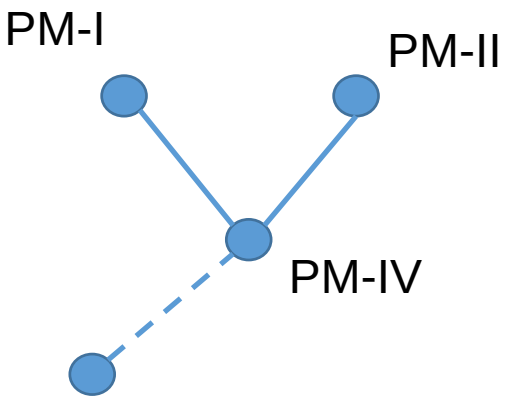
$$\sum_i x_{iq}^{PM} - x_{q\in Q'} M \leq 0 \quad \forall q \in Q_{TRL<8}$$

$$M \sum_i x_{iq}^{PM} - x_{q\in Q'} \leq 0 \quad \forall q \in Q_{TRL<8}$$

$$C_{req}^{PM} x_{iq}^{PM} \leq C_{cap}^{PM} x_{iq}^{PM} \quad \forall q \in Q_{TRL<4}$$

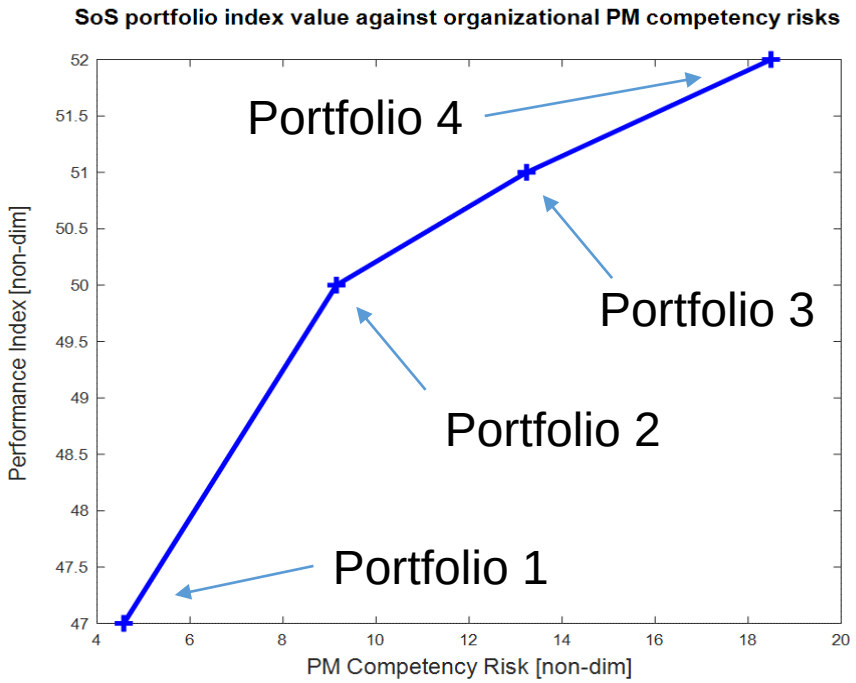
$$C_{req}^{PM} x_{iq}^{PM} \leq E_{\max}$$

$$\sum_t x_{tq}^{PM} \leq 1 \qquad \forall q \in Q \quad t=1\ldots 4$$



$$x_{cij} \in \textit{real, integer}, x_q^B \in \textit{binary}, x_{iq}^{PM} \in \textit{binary}, x_{ij} \in \textit{binary}$$

Concept Problem - Results



PM Type	Population	Average Risk
I	2	4.1
II	2	5.3
III	2	4.7
IV	2	10.1

		Portfolio			
		1	2	3	4
No.	Candidate Systems				
1	Control Station 1	-	-	-	-
2	Control Station 2	-	-	-	-
3	Control Station 3	-	-	-	-
4	Control Station 4	-	-	-	-
5	Control Station 5	X	X	X	X
6	First Satellite 1	-	-	-	-
7	First Satellite 2	X	-	-	-
8	First Satellite 3	-	-	-	-
9	First Satellite 4	-	-	X	X
10	First Satellite 5	-	X	-	-
11	UAV-1	-	-	-	-
12	UAV-2	X	X	X	X
13	UAV-3	-	-	-	-
14	UAV-4	-	-	-	-
15	UAV-5	-	-	-	-
16	Carrier Ship -1	-	-	-	-
17	Carrier Ship -2	X	X	X	-
18	Carrier Ship -3	-	-	-	X
19	Second Satellite 1	-	-	-	-
20	Second Satellite 2	X	X	-	-
21	Second Satellite 3	-	-	-	X
22	Second Satellite 4	-	-	X	-
23	Second Satellite 5	X	X	X	X
Program Manager Type		# of PMs (system # PM allocated to)			
	I	-	-	1 (9)	
	II	-	-	-	2(9,21)
	III	1 (23)	2 (23,10)	2(22,23)	2(18,23)
	IV	-	-	-	-

Summary and Recommendations

- Potential approach of using quantitative and qualitative means cohesively to select optimal product architecture and organizational architecture

- Future work
  - Expand modeling of organizational model components and dimensions
  - Potentially incorporate MBSE, PLM artifacts in both organizational and product elements
  - Account for uncertainty more explicitly within the decision-making framework

Acknowledgement

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References

1. Defense Acquisition University, “Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System”, 2009.
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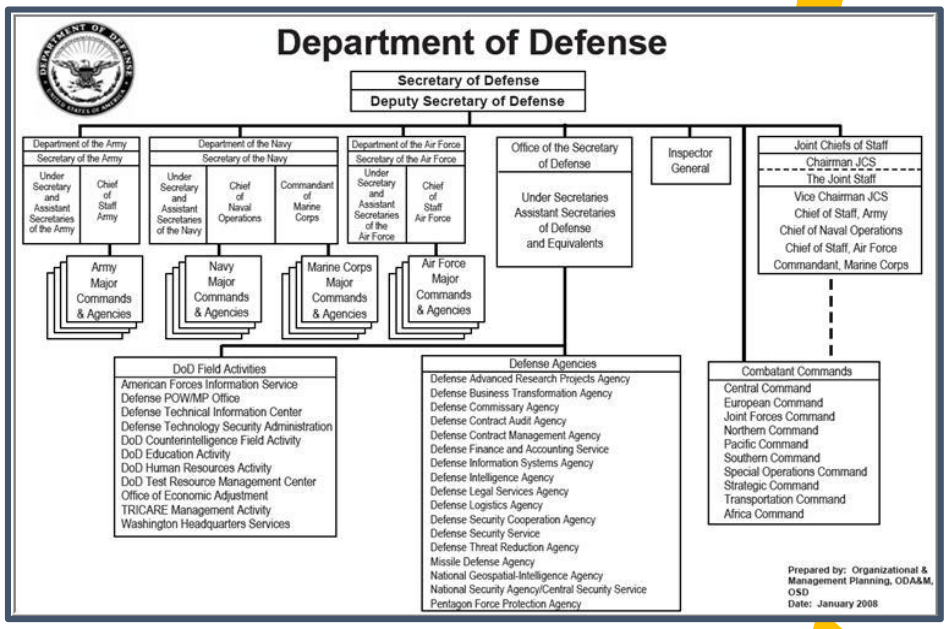
3. DeLaurentis, D., “Optimal Selection of Organizational Structuring for Complex System Development and Acquisitions”, *FY15 Acquisition Research Program*, 2015.
4. Honda, T., Ciucci, F., Lewis, K., Yang, M., “Comparison of Information Passing Strategies in System-Level Modeling”, *AIAA Journal*, Vol. 53, No. 5, 2015, pp. 1121-1133.
5. MacCormack, A., Baldwin, C., Rausnak, J., “Exploring the duality between product and organizational architectures: A test of the “mirroring” hypothesis”, *Elsevier*, No. 41, 2007, pp. 1309-1324.
6. Wood, R., “How well are PMs Doing? Industry View of Defense Program Manager Counterparts”, *Defense Acquisition University*, 2010 pp. 206-218.

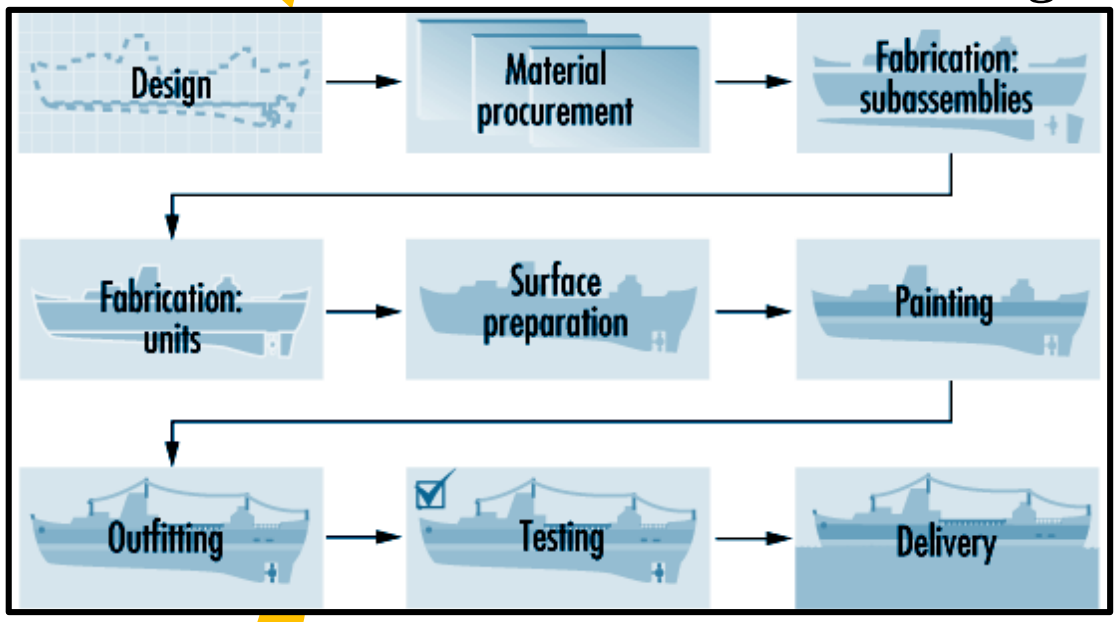
Extras

Idea of Solution

Organizational Design



Product Design



Create a framework for co-design of the organizational structure and product structure utilizing methods of operations research, statistical techniques and psychological sciences

What: Conceptual Problem
DoD System Acquisition Life Cycle

- Why focus on DoD system acquisition?

GAO-04-635T
Future Combat Systems

GAO-06-110
Better Support of Weapon System Program Managers Needed to Improve Outcomes

GAO-16-489T
F-35 Joint Strike Fighter

GAO-14-77
Cancelled DoD Programs: DOD Needs to Better Use Available Guidance and Manage Reusable Assets

GAO-08-674T
Defense Acquisitions Results of Annual Assessment of DoD Weapons Programs
(Average program delay of 21 months)

GAO-12-400SP
Assessments of Selected Weapons Programs

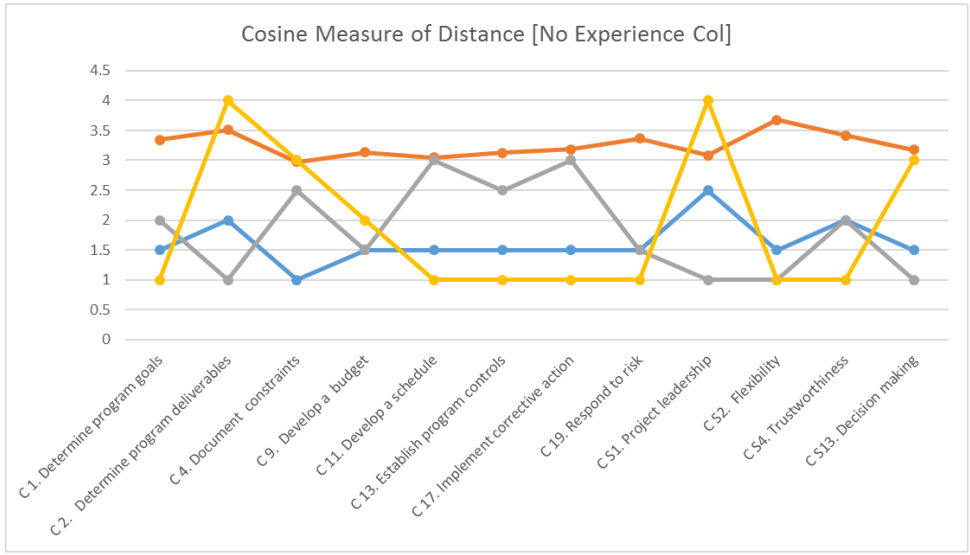
The Life Cycle aligned with the “hard” skills evaluated in the program manager survey
(i.e. Determine program goals, Create a WBS, Develop a budget, etc.)

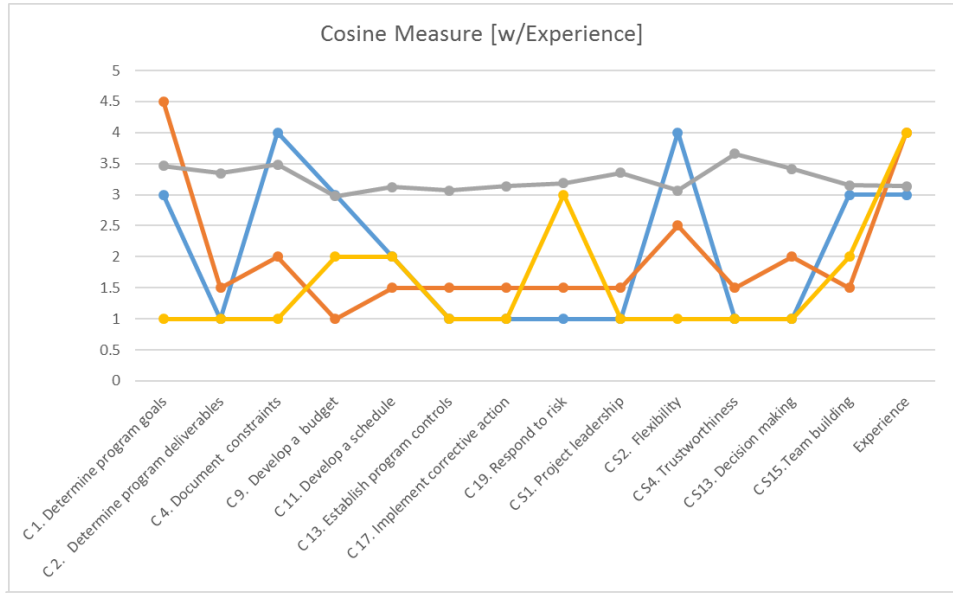
What: Organizational Design Data

- Roy Wood survey of 146 DoD program managers by their industry counterparts
  - 35 “hard” and “soft” competencies evaluated on:
    - Performance in the competency
    - Importance of the competency

Top 15 competencies sized by their rank in Performance

References: Wood (2010)


Cosine Measure of Distance [No Experience Col]
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
C 1. Determine program goals
C 2. Determine program deliverables
C 4. Document constraints
C 9. Develop a budget
C 11. Develop a schedule
C 13. Establish program controls
C 17. Implement corrective action
C 19. Respond to risk
CS1. Project leadership
CS2. Flexibility
CS4. Trustworthiness
CS13. Decision making


Cosine Measure [w/Experience]
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C 1. Determine program goals
C 2. Determine program deliverables
C 4. Document constraints
C 9. Develop a budget
C 11. Develop a schedule
C 13. Establish program controls
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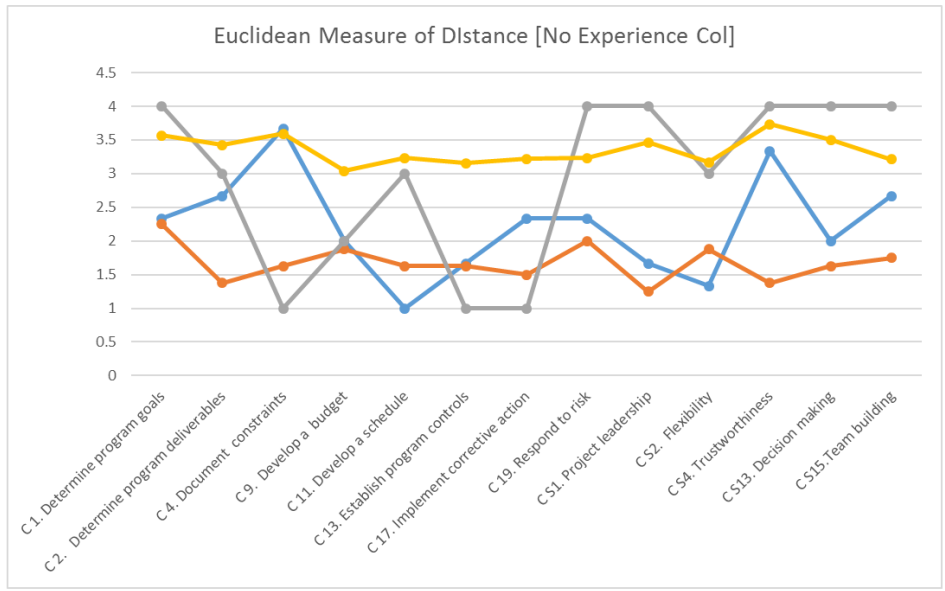
C 19. Respond to risk
CS1. Project leadership
CS2. Flexibility
CS4. Trustworthiness
CS13. Decision making
CS15.Team building
Experience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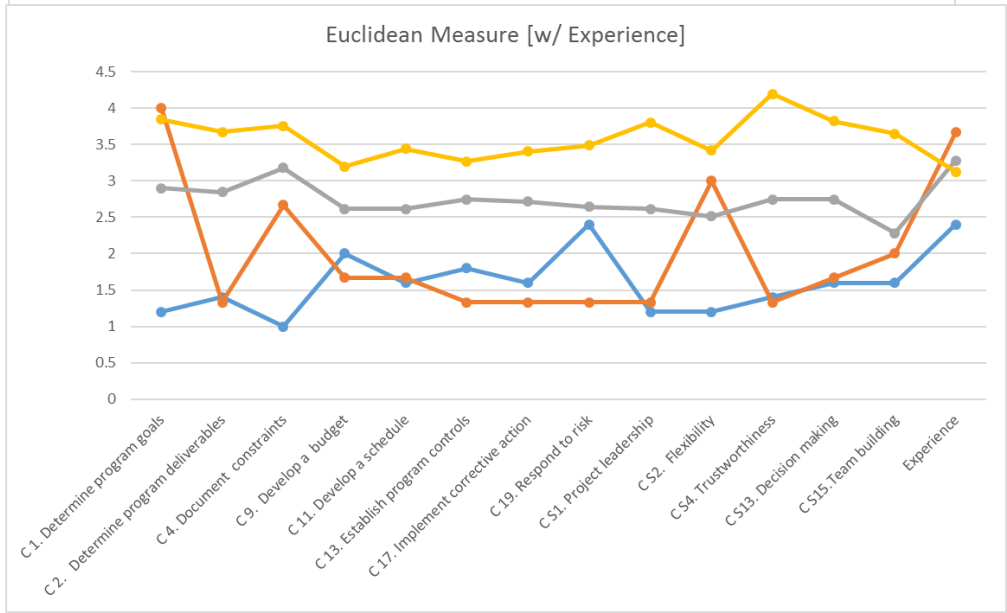
Euclidean Measure [w/ Experience]
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4
3.5
3
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1.5
1
0.5
0
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Experience