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Knowledge and Skills for Enterprise Transformation.

Addressing Cost Increases in Evolutionary Acquisition

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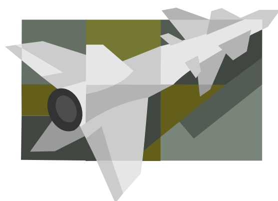
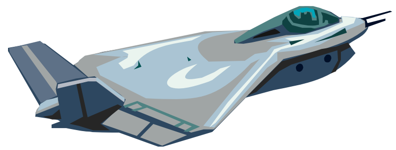
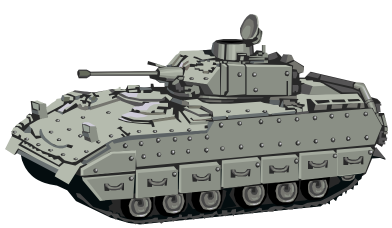
Agenda

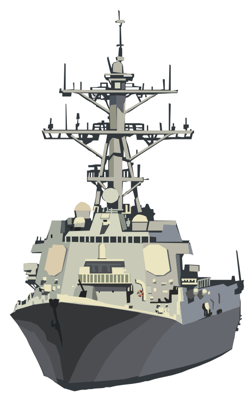
- Motivation
- Hypotheses and questions
- Model
- Experiment
- Cost implications
- Conclusions

Motivation









- Fiscal issues are making high cost problematic for system acquisition
- Cost growth has been cited as a major problem with growing political focus
- Evolutionary acquisition (EA) was adopted, in part, to address cost
- Sustainment is an increasingly important part of the acquisition lifecycle (approximately 60% of lifecycle cost)

Previous Research

- Evolutionary acquisition can lead to higher overall cost
  - Due to more refresh cycles
- System modularity can reduce sustainment cost due to lower costs for repairs and technology upgrades
  - Modularity is the degree to which components of a system are related to one other, or connected to one another
  - In a non-modular system, changes to one component may necessitate changes to another (if they are related)
  - Modularity is usually conceptualized as a matrix showing the relationships between components
  - Infrastructure may exist

1.0	1.0	1.0	1.0	1.0	1.0
0.0	1.0	0.3	0.0	0.0	0.0
0.0	1.0	1.0	0.0	0.3	0.5
0.0	0.5	1.0	1.0	0.0	0.0
0.0	0.0	0.0	0.0	1.0	0.0
0.0	0.0	0.0	0.0	0.0	1.0

- Repair matrix R_k
- Component r_{ijk} = probability that repair to component *i* causes repair to component *j*
- Similar matrix for upgrades

Hypotheses

- Research literature
  - Increased modularity decreases the cost of implementing technology upgrades for deployed systems
  - Increased modularity decreases the mean time to repair a failed system component and potentially the cost for the repair
  - Increased modularity increases systems engineering cost associated with system development.
- This research
  - What is the trade-off between increased development cost versus decreased sustainment cost?
  - What is the impact on this trade-off of the system production level?

Model Overview

- Discrete-event simulation model implemented in ARENA
- Three acquisition sub-models
  - System model – the system being acquired
  - Procurement model – the processes through which a system is procured
  - Sustainment model – the processes through which a system is sustained
- Exogenous model – external organizations and effects
  - DoD S&T enterprise
  - External technology progress

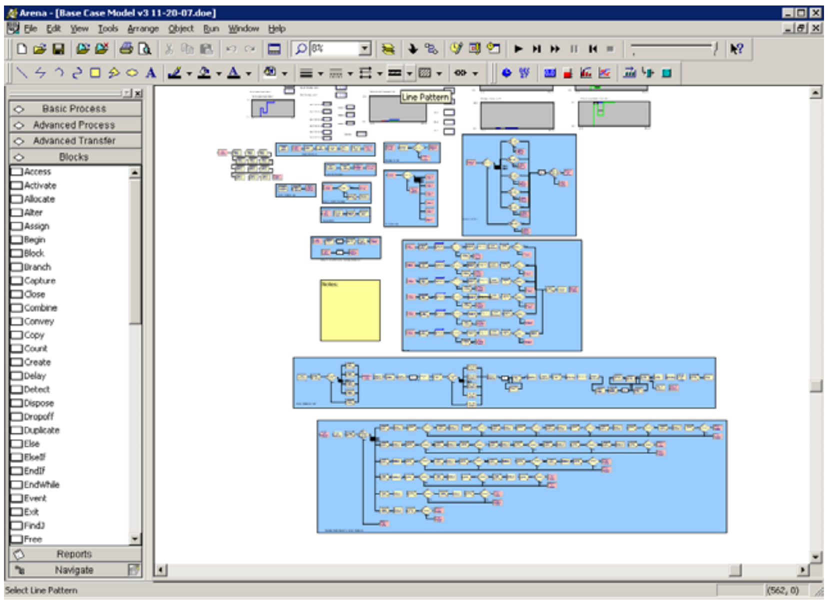
System Model

1.0	1.0	1.0	1.0	1.0	1.0
0.0	1.0	0.3	0.0	0.0	0.0
0.0	1.0	1.0	0.0	0.3	0.5
0.0	0.5	1.0	1.0	0.0	0.0
0.0	0.0	0.0	0.0	1.0	0.0
0.0	0.0	0.0	0.0	0.0	1.0

$$m_{rk} = \frac{1}{(k-1)(k-2)} \sum_{i=2}^{n_k} \sum_{j=2, j \neq i}^{n_k} r_{ijk}$$

- Technologies
  - Application area
  - Maturity
  - Capability
- Modularity
  - Extent to which system components affect one another
  - Repair and technology upgrades
  - Modularity index
- Production level

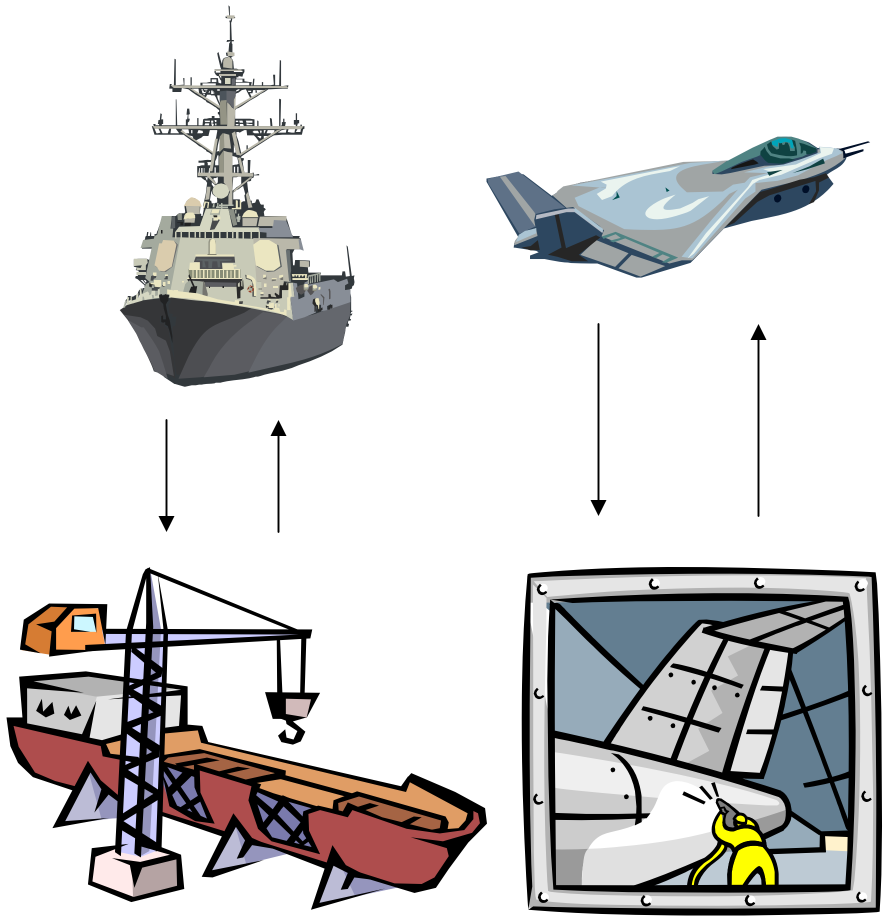
Procurement Model



- Concept development
- Technology development
  - Develop technologies within a program vs. accept only mature technologies
- System development
  - Exponentially increasing effort (cost and time) needed to make a system more modular
- Production & deployment
  - Cobb-Douglas production function with increasing returns to scale based on production level

Sustainment Model

- Repair and technology upgrade processes
- Poisson arrival process assumed
  - Component failure rate
  - Upgrade opportunity rate
- Modularity impacts whether a repair/upgrade to component *i* causes one to component *j*
- No effect from mission profile on arrival rates
- Costs based on individual transactions over fleet
- Costs are scaled to be 25% of sustainment budget
- Fleet is assumed to equal production level



Experimental Design

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- Independent variables
  - Acquisition policy (traditional vs. evolutionary)
  - Modularity index (0.50 vs. 0.25)
  - Production level (250 vs. 500)
- Dependent variables
  - Program procurement cost
  - Program sustainment cost
  - Total program cost
  - Annualized procurement cost (over all systems)
  - Annualized sustainment cost (over all systems)
  - Annualized total cost (over all systems)
- 2^3 factorial experiment for each dependent variable

Simulation Details

- Ten replications of each factor combination were conducted for statistical significance
- Each replication consist of 150 years of simulated time, with a prior 50 year warm-up period to reach steady state

Summary Results

Run	Pol.	Mod.	Prod.	P-P	P-S	P-T	A-P	A-S	A-T
1	T	0.50	250	12,657	22,248	34,906	5,305	5,075	10,380
2	T	0.50	500	18,640	26,409	45,049	6,378	5,653	12,031
3	T	0.25	250	13,832	20,623	34,455	5,378	4,441	9,819
4	T	0.25	500	20,078	23,096	43,174	6,189	4,296	10,485
5	E	0.50	250	11,518	22,248	33,766	5,960	6,316	12,276
6	E	0.50	500	17,548	26,409	43,957	7,071	6,556	13,627
7	E	0.25	250	12,629	20,623	33,252	5,884	5,210	11,094
8	E	0.25	500	18,910	23,200	42,109	6,981	5,290	12,271

P-P: Program procurement cost
P-S: Program sustainment cost
P-T: Total program cost

A-P: Annualized procurement cost
A-S: Annualized sustainment cost
A-T: Total annualized cost

Cost figures in millions $

Analysis

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- Statistical analysis is performed using balanced analysis of variance (ANOVA) method
- This allows detection of significant effects on dependent variables from
  - Independent variable factors (e.g., acquisition policy)
  - Interactions between factors

Program Cost

- Procurement
  - Evolutionary acquisition tends to lower procurement cost, due to lower technology development costs.
  - High levels of modularity tend to escalate procurement cost, due to higher systems engineering costs.
  - High modularity and high production levels interact to increase procurement more than single factor effects.
- Sustainment
  - Low modularity tends to increase sustainment cost due to increased repairs and upgrades.
  - High modularity mitigates the increased sustainment cost associated with high production levels.
- Overall
  - High modularity tends to lower overall acquisition cost and mitigates the overall cost associated with high production.

Annualized Enterprise Cost

- Procurement
  - Evolutionary acquisition tends to increase procurement cost, due to increased refresh cycles.
  - Low levels of modularity tend to increase procurement cost. High modularity lengthens development times, resulting in fewer systems being deployed.
  - Low modularity and high production interact to increase cost.
  - Increased number of programs under evolutionary acquisition interacts significantly with high production to increase annualized cost.
- Sustainment
  - High modularity results in reduced sustainment cost.
  - An increased number of programs under evolutionary acquisition leads to higher sustainment costs.
  - High modularity mitigates the increased cost of high production levels.
- Overall
  - High modularity tends to lower overall acquisition cost and mitigates the overall cost associated with high production.

Implications for EA

- Based on consideration of results for evolutionary acquisition only (2^2 experiment).
- Modularity had similar effects under evolutionary acquisition as in the overall experiment.
- The interaction effect between modularity and production level is weaker for evolutionary acquisition than for traditional.
- This implies that the interaction effect is experienced mainly in traditional acquisition.

Conclusions

- Increases in system modularity can result in overall cost reduction, as cost decreases in sustainment overpower cost increases in development. This points to the importance of upstream investments.
- Modularity can help mitigate cost increases associated with higher production levels.
- Evolutionary acquisition is less susceptible to this effect, especially from an annualized cost perspective.
- Evolutionary acquisition may decrease individual program costs, but can increase overall annualized cost. Thus, discretion should be used in refresh cycles.

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Questions

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Back-Up Slides

Program Procurement

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Source	DF	SS	MS	*F*	*p*
Policy	1	26486575	26486575	384.31	0
Mod	1	32315116	32315116	468.88	0
Prod	1	752794480	752794480	10922.85	0
Policy*Mod	1	24451	24451	0.35	0.553
Policy*Prod	1	8505	8505	0.12	0.726
Mod*Prod	1	330508	330508	4.8	0.032
Policy*Mod*Prod	1	207	207	0	0.956
Error	72	4962185	68919		
Total	79	816922028			

Program Sustainment

Source	DF	SS	MS	*F*	*p*
Policy	1	13394	13394	0.01	0.933
Mod	1	119354720	119354720	63.02	0
Prod	1	223440510	223440510	117.97	0
Policy*Mod	1	13394	13394	0.01	0.933
Policy*Prod	1	13394	13394	0.01	0.933
Mod*Prod	1	13382709	13382709	7.07	0.01
Policy*Mod*Prod	1	13394	13394	0.01	0.933
Error	72	136366569	1893980		
Total	79	492598085			

Total Program Cost

Source	DF	SS	MS	*F*	*p*
Policy	1	25308713	25308713	12.6	0.001
Mod	1	27460953	27460953	13.67	0
Prod	1	1796490516	1796490516	894.42	0
Policy*Mod	1	1651	1651	0	0.977
Policy*Prod	1	43247	43247	0.02	0.884
Mod*Prod	1	9506987	9506987	4.73	0.033
Policy*Mod*Prod	1	10271	10271	0.01	0.943
Error	72	144615531	2008549		
Total	79	2003437868			

Annualized Procurement

Source	DF	SS	MS	*F*	*p*
Policy	1	8745812	8745812	853.98	0
Mod	1	99301	99301	9.7	0.003
Prod	1	20921804	20921804	2042.9	0
Policy*Mod	1	3027	3027	0.3	0.588
Policy*Prod	1	131703	131703	12.86	0.001
Mod*Prod	1	94557	94557	9.23	0.003
Policy*Mod*Prod	1	78033	78033	7.62	0.007
Error	72	737368	10241		
Total	79	30811604			

Annualized Sustainment

Source	DF	SS	MS	*F*	*p*
Policy	1	19079848	19079848	134.12	0
Mod	1	23789768	23789768	167.23	0
Prod	1	707084	707084	4.97	0.029
Policy*Mod	1	181790	181790	1.28	0.262
Policy*Prod	1	16048	16048	0.11	0.738
Mod*Prod	1	971557	971557	6.83	0.011
Policy*Mod*Prod	1	397276	397276	2.79	0.099
Error	72	10242758	142261		
Total	79	55386129			

Total Annualized Cost

Source	DF	SS	MS	*F*	*p*
Policy	1	53661197	53661197	292.72	0
Mod	1	26963050	26963050	147.08	0
Prod	1	29321345	29321345	159.95	0
Policy*Mod	1	231729	231729	1.26	0.265
Policy*Prod	1	55804	55804	0.3	0.583
Mod*Prod	1	1672308	1672308	9.12	0.003
Policy*Mod*Prod	1	827448	827448	4.51	0.037
Error	72	13199104	183321		
Total	79	125931985			