Modularity and Adaptability in Future U.S. Navy Ship Designs

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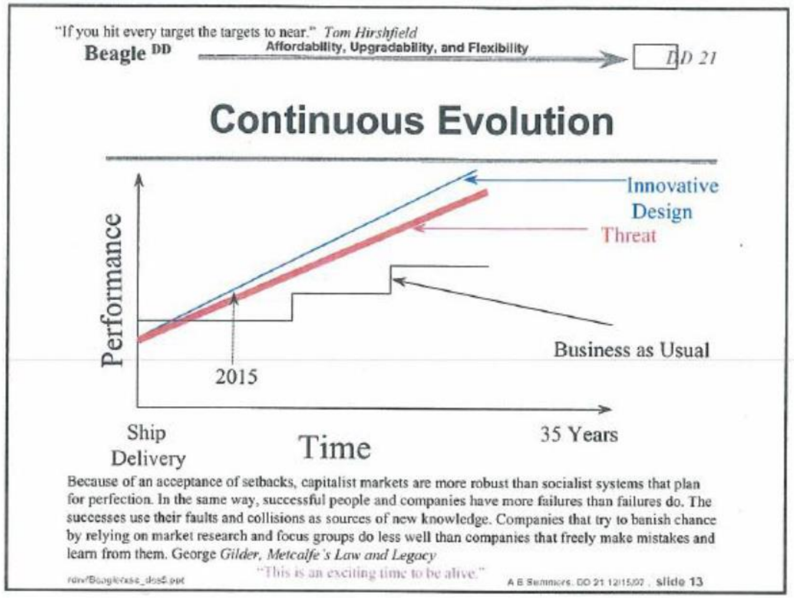
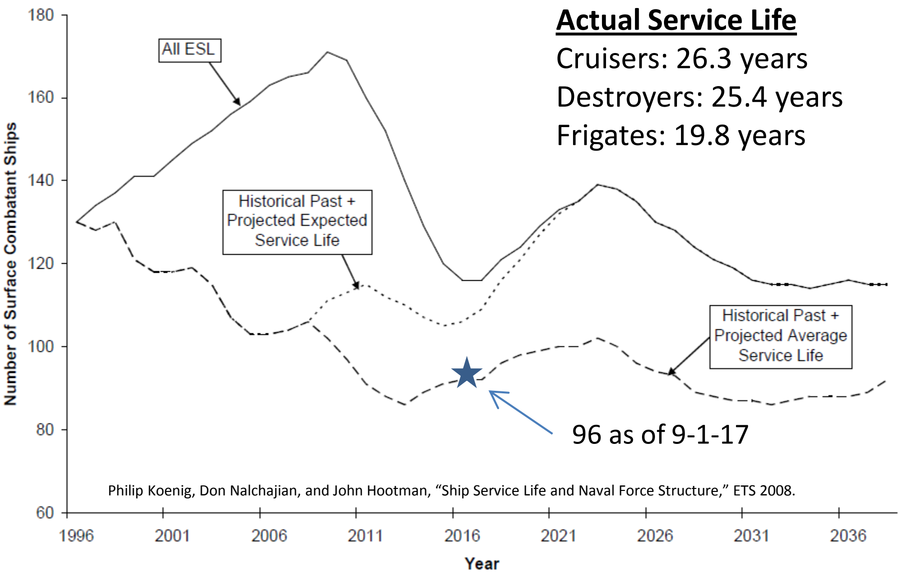
MECON 2017
November 21-23, 2017
Hamburg, Germany

Motivation





Since World War II, the Navy has not been successful in keeping surface combatants operationally relevant for their design service life.

Modularity and Flexibility technologies that can help keep ships operationally relevant have been well known since mid 70's, but have not been systematically adopted

Current requirements and decision processes do not inherently consider the value of modularity and flexibility in keeping ships operationally relevant

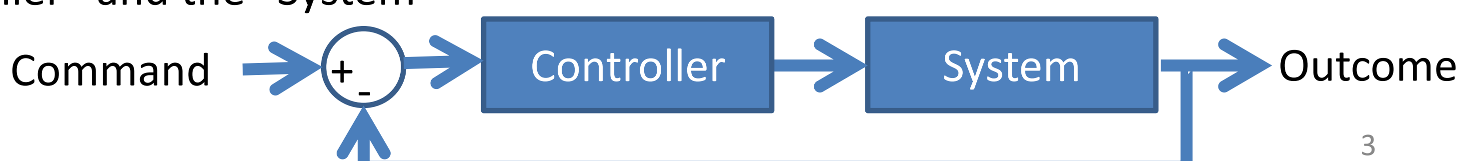
Can REAL OPTIONS THEORY help?

Open-Loop vs Closed-Loop Systems

- Current Acquisition System acts like an open-loop system
  - Command = Requirements
  - Must get the requirements (aim point) nearly perfect for good outcome (but the target is moving fast and changing directions)
- Flexible-Adaptable Acquisition allows in-service course correction
  - "Control authority" becomes a more important attribute
  - System is corrected in-service to respond to changing needs.
    - Aim point is automatically corrected by feedback to hit the target
  - Real Options Analysis provides guidance for designing the "Controller" and the "System"

Open Loop

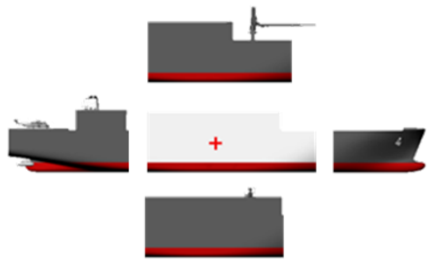
Closed Loop



Modular, Adaptable, Flexible Ship Technologies

Service Life Allowances
Planned Access Routes
Standard Interfaces

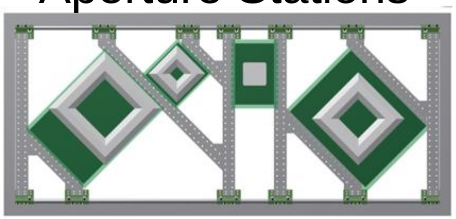
Modular Hull Ship



Off-Board Vehicles

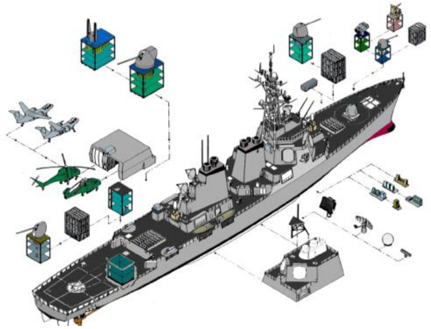
Mission Packages

Aperture Stations

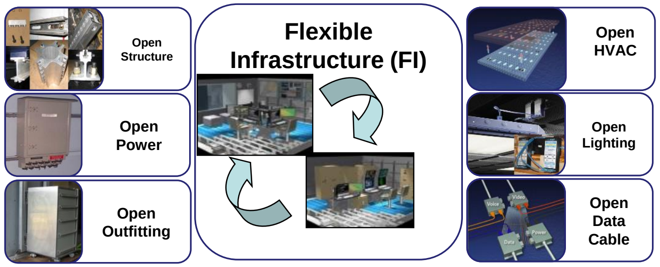


Mission Bay

Weapons Modules



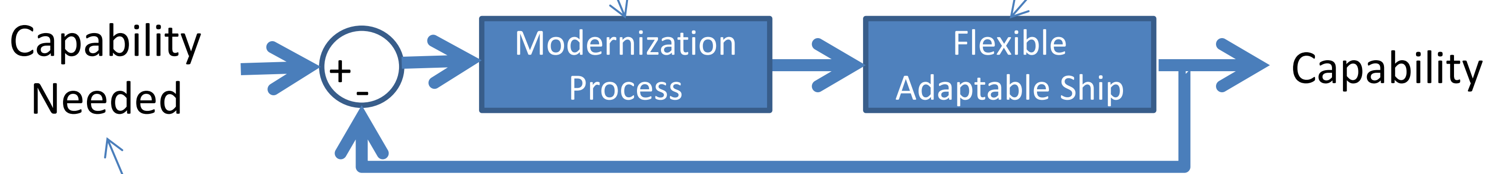
Flexible Infrastructure



Need to rapidly evolve a ship over its service life to reflect evolving needs

Science & Technology
Research & Development
Configuration Design
Budgeting
Program Management

Flexible Features
Modularity
Service Life Allowances
to enable adaptability



Intelligence – Adversary Capabilities
Force Architecture analysis
Changing Concepts of Operation (CONOPS)

Real Options Analysis

- An "Option" is the right to buy or sell an asset for a given price on or before a given date.
  - Options must be purchased
  - Options have an expiration date
  - Options enable deferring a decision
- Real Options Analysis
  - Provides insight on the value of an option to determine if purchasing it is advantageous
  - Can be better than traditional Net Present Value analysis
    - Recognizes that not all pertinent information is available at time of purchase
    - Accounts for volatility and unknowns
    - Recognizes that managers can make better decisions when pertinent information becomes known.

Options "ON" versus Options "IN"

- Options "on" are reactive
  - Can always modernize even if modularity and flexibility features not incorporated.
  - Includes option to "abandon" which results in ships not meeting expected service life.
- Options "in" are proactive
  - Features paid for up front to enable managers to make affordable decisions in the future as uncertainty resolves.

Real Options Analysis helps determine the type and quantity of Options "in" that should be incorporated in a ship design

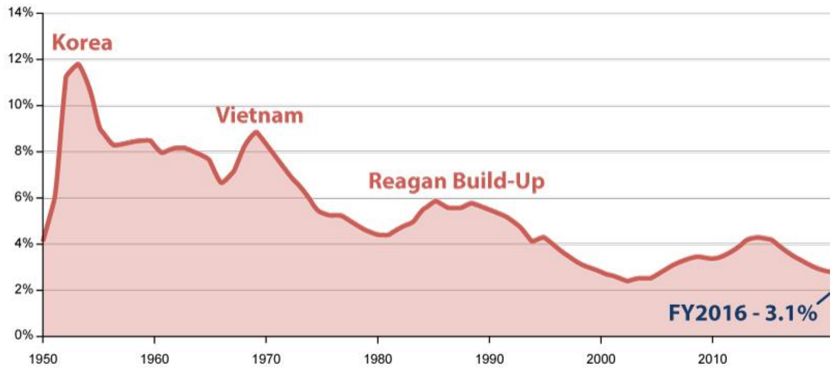
Prerequisites for successful use of Real Options

- A financial model must exist
- Uncertainties must
  - exist
  - affect decisions when leadership is actively managing the project
  - affect the results of the financial model
- Management must
  - have strategic flexibility or options make mid-course corrections when actively managing the projects
  - be smart enough and credible enough to execute the options when it becomes optimal to do so

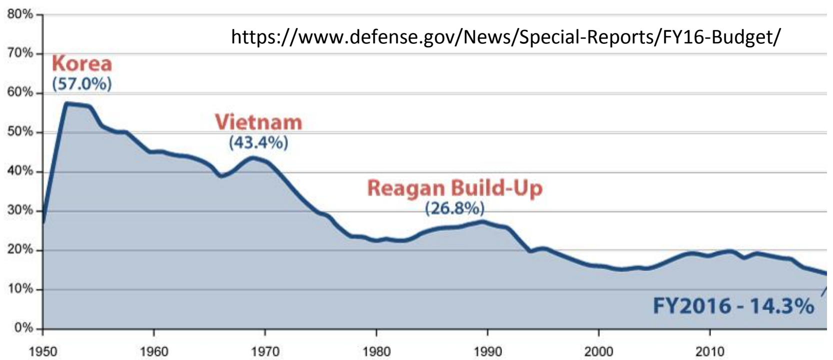
Mun, J. 2006. Real Options Analysis, 2nd ed. Hoboken, N.J.: John Wiley & Sons.

Affordability

- Affordability is the willingness to spend budget authority on a system.
- Depends on
  - Relative value with respect to other investments
  - Geopolitical Threat
  - Fiscal Environment
  - Industrial Base

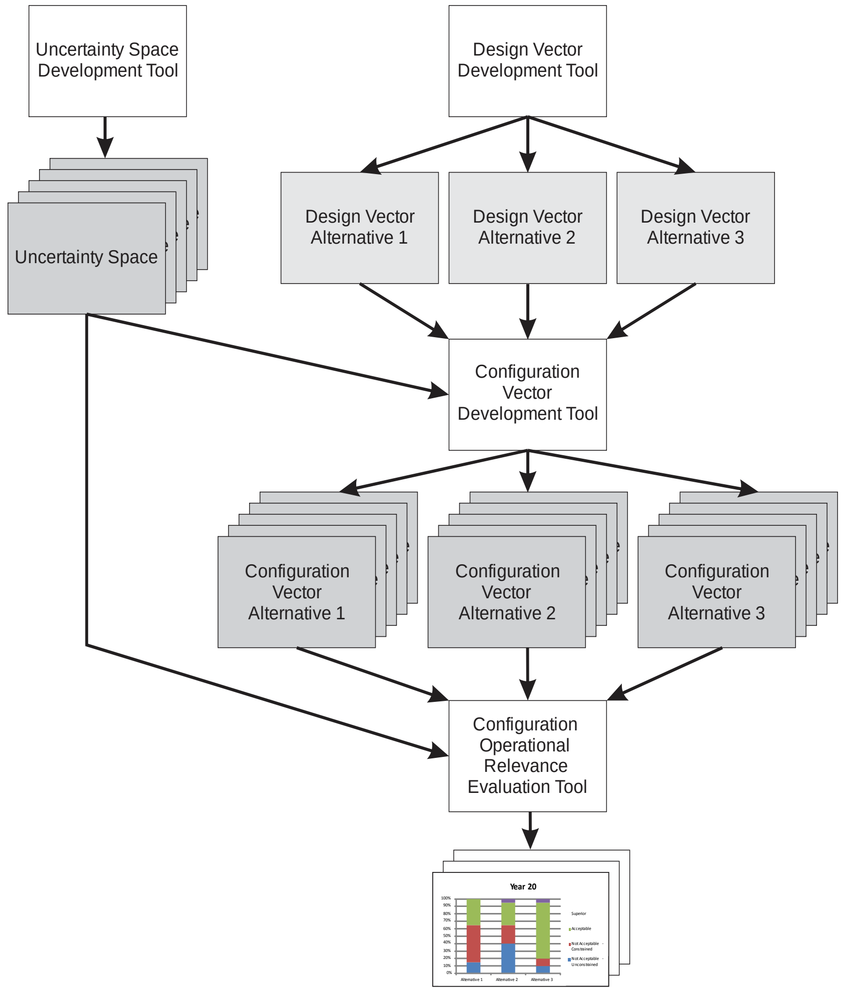


Defense Spending as a Share of the Economy (GDP)



Defense Spending as a Share of Total Federal Spending

Proposed Process

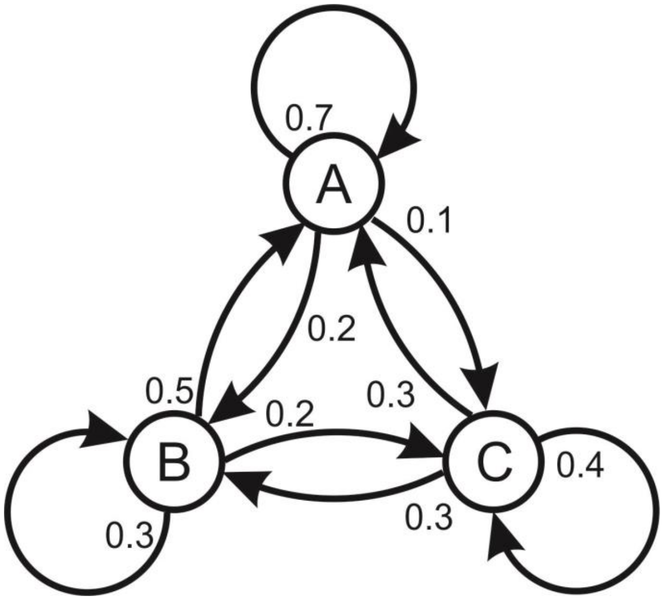


Uncertainty Space

- Defines the environment in which the configuration vector evolves
  - World conflict state
    - Establishes Affordability constraints
    - Establishes severity of capability gaps
  - Potential adversary capabilities
  - Availability of key technologies
- Evaluated periodically
  - Typically Annually
- May be modeled as a Markov Chain
  - The values for this year depend stochastically only on the values for the prior year.

UNCERTAINTY SPACE			
World Conflict State	Peace	Adversary 1 ASW level	8
Adversary 1 conflict	No	Adversary 1 AAW level	7
Adversary 2 conflict	No	Adversary 1 SW level	7
Adversary 3 conflict	No	Adversary 2 ASW level	4
		Adversary 2 AAW level	5
Key Technology 1 available	No	Adversary 2 SW level	3
Key Technology 2 available	No	Adversary 3 ASW level	2
Key Technology 3 available	No	Adversary 3 AAW level	5
Key Technology 4 available	No	Adversary 3 SW level	5

Markov Chains



$$P = \begin{bmatrix} 0.7 & 0.5 & 0.3 \\ 0.2 & 0.3 & 0.3 \\ 0.1 & 0.2 & 0.4 \end{bmatrix}$$

$$x_{n+1} = Px_n$$

Year	Chain A	Chain B	Chain C	Chain D	Chain E
2030	1	3	3	4	2
2031	1	3	3	4	2
2032	1	3	3	4	2
2033	1	3	3	2	2
2034	1	3	4	2	2
2035	1	3	4	2	2
2036	1	3	4	2	3
2037	2	3	4	3	3
2038	3	2	3	1	3
2039	3	2	3	2	3
2040	2	2	3	2	3

$$\begin{bmatrix} 1 = \ Peace \\ 2 = \ Preparing\ for\ Conflict \\ 3 = \ Regional\ Conflict \\ 4 = \ Major\ War \end{bmatrix}$$

$$P = \begin{bmatrix} 0.88 & 0 & 0.09 & 0.06 \\ 0.09 & 0.82 & 0.09 & 0.06 \\ 0 & 0.12 & 0.79 & 0.13 \\ 0.03 & 0.06 & 0.03 & 0.75 \end{bmatrix}$$

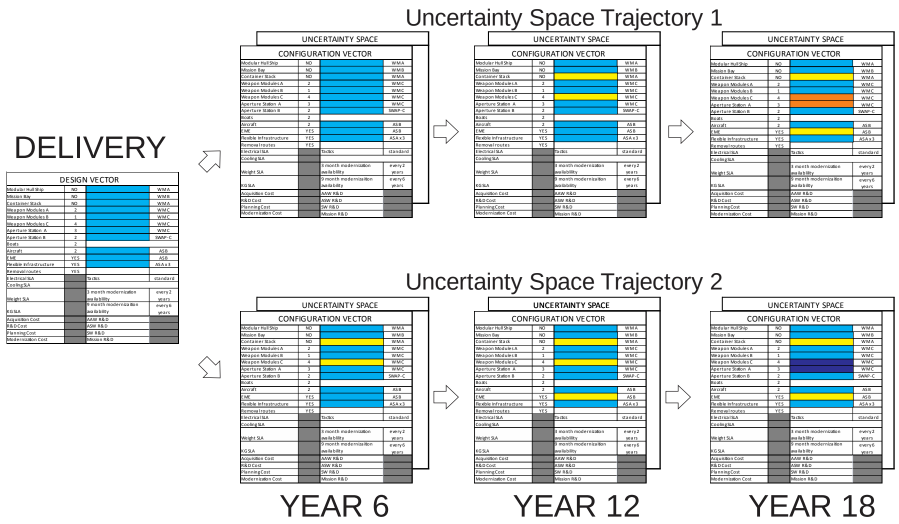
Design Vector

- Consists of
  - Initial Ship Configuration at delivery
  - Initial set of tactics
  - Modernization process
- The Design Vector is the starting point for the Configuration Vector
- A study would normally compare multiple Design Vector alternatives
  - Evaluate the associated configuration vectors within multiple Uncertainty Spaces to determine performance
  - Statistics of the multiple configuration vectors are used to compare Design Vector alternatives.

DESIGN VECTOR			
Modular Hull Ship	NO	64 cell VLS	WM A
Mission Bay	NO	32 cell VLS	WM B
Container Stack	NO	5 inch gun	WM A
Weapon Modules A	2	37 mm gun	WM C
Weapon Modules B	1	37 mm gun	WM C
Weapon Modules C	4	SEA-RAM	WM C
Aperture Station A	3	CIWS	WM C
Aperture Station B	2	ATT	SWAP-C
Boats	2		
Aircraft	2	SPS-64	AS B
EME	YES	SPS-67	AS B
Flexible Infrastructure	YES	SPY-1D	AS A x 3
Removal routes	YES		
Electrical SLA	1 MW	Tactics	standard
Cooling SLA	280 tons		
Weight SLA	800 mt	3 month modernization availablility	every 2 years
KG SLA	.5 meters	9 month modernizaition availability	every 6 years

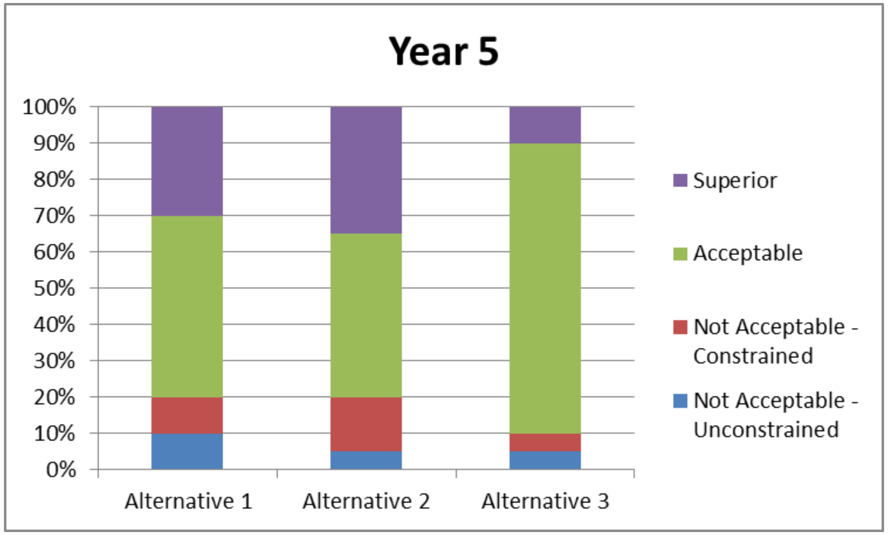
Configuration Vector

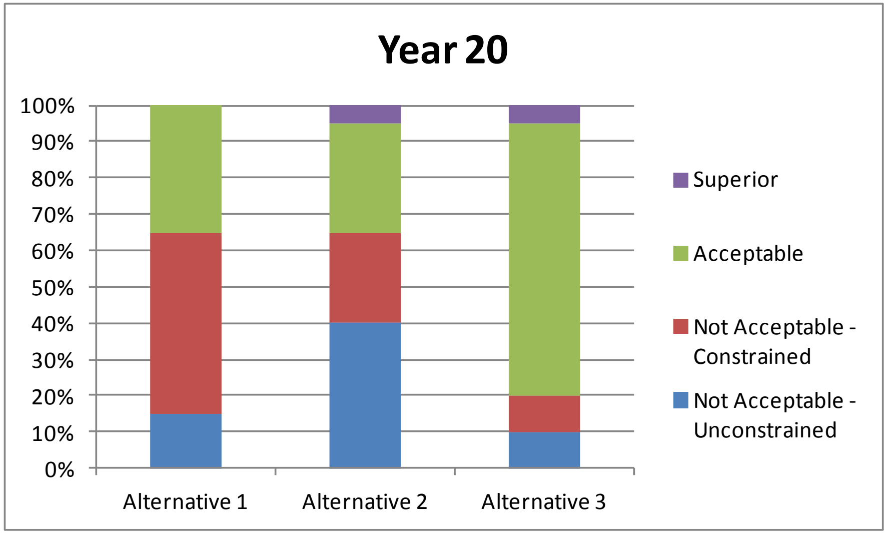
- Describes the evolution of the design vector over time
  - Evolves in response to the Uncertainty Space
  - Different Uncertainty Space trajectories result in different configuration vectors
- Evaluated over time to assess operational relevance
  - Superior: Capability is much greater than needed
  - Acceptable: Capability is sufficient to perform mission
  - Not Acceptable Constrained: Capability is not sufficient to perform mission, but would be if sufficient resources or time provided
  - Not Acceptable Unconstrained: Capability is not sufficient to perform mission, but technology does not exist to achieve capability



Results

- Configuration vectors for each alternative design vectors developed and evaluated for a set of uncertainty space vectors.
- For each year, the fraction of configuration vectors in each category is displayed.
  - Design Vector alternatives with high percentages of Superior and Acceptable performance are desirable.
  - Design Vector alternatives with high percentage of Not Acceptable performance are at risk of being retired prior to the design service life





Summary

- Cannot evaluate the value of modularity, flexibility, and adaptability by only examining the ship design.
- Must also consider
  - How gaps are identified.
  - How technology is developed.
  - How ship configurations are adapted to close the gap.
  - How resource constraints impact the response to a gap.
- Real Options Analyses conducted using the proposed framework promises to provide the fleet with more capability when that capability is most needed.
- Compare design alternatives by comparing statistics of configuration vector capability gaps evaluated over many uncertainty spaces.