# Applying Principles of Set-Based Design to Improve Ship Acquisition

Eric Rebentisch, Ph. D.
Massachusetts Institute of Technology
77 Massachusetts Ave., Room E17-345
Cambridge, MA 02139-4307
erebenti@mit.edu
Phone: 617-258-7773

LCDR John Genta
Portsmouth Naval Shipyard
john.a.genta@navy.mil
jagenta@alum.mit.edu
Phone: 207-451-8923



# Motivation: Designing an affordable fleet

*"The lack of discipline in both the requirements development process and the systems design and demonstration process are making new ships unaffordable" D. Hunter, R-CA, 2004*

*"The basic problem is that the naval ship enterprise lacks the mature capabilities for the consistent design, acquisition and construction of cost-effective, mission capable warships" R. Keane, 2009*

*"…Do more, without more!" Deputy USD, Better Buying Power, 2015*

## The Solution: Improve the navy ship design/acquisition process

- USN design improvement initiatives
  - 2005: NSRP SIP
  - 2007, COMNAVSEA Direction
  - 2008, 2 Pass/6 Gate design process
  - 2009, NAVSEA Ship Design Tool TWH created
- DoD Process Initiatives
  - 2009, WSARA
  - 2012+, Better Buying Power Series
  - 2013, Annual DoD Acquisition Performance Reviews

# Set-based design (SBD)

- Identified with Toyota's product development process—thought of by many as "Lean product development"
- SBD considers a wider range of alternative sets in a design space in parallel—an optimal design is developed by rapidly converging on a preferred solution
- Relatively higher resource allocation at the front-end of projects for analyzing, prototyping, and testing multiple solutions to gather knowledge and reduce uncertainties, with the promise that the overall process will be more resource-efficient
- The knowledge obtained in the process is captured for future reuse
- In studies, the benefits of SBD are:

1. Up to 75% reduction in project cost, 50% reduction in lead time, 50-75% improvement in product technical performance (innovation), and 50-100 % reduction in warranty cost and number of engineering changes
2. 30% material and manufacturing cost reductions

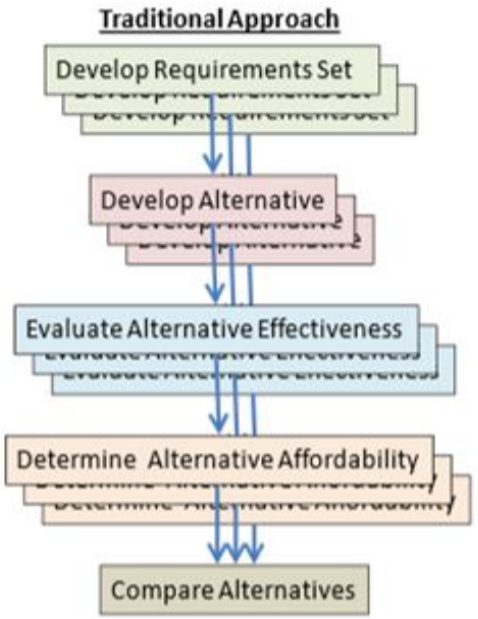
USN experiments with SBD in recent years have been promising and its application is expanding

# PBD vs SBD

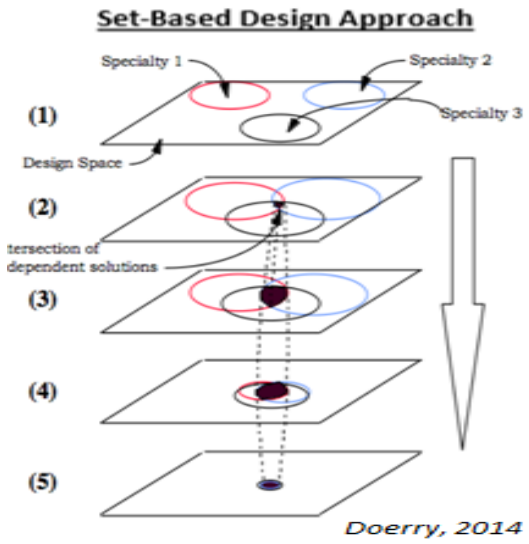
## Point Based Design Process

1. Research the problem and set requirements.
2. Use experience to quickly determine a large variety of potential solutions.
3. Perform preliminary analysis to determine a single, feasible, most opportunistic solution.
4. The chosen concept is then modified in detail.
5. If the detailed design cannot be modified to meet all requirements, the process starts over at step 1 or 2 until a solution is found.




## Set-Based Design Principles

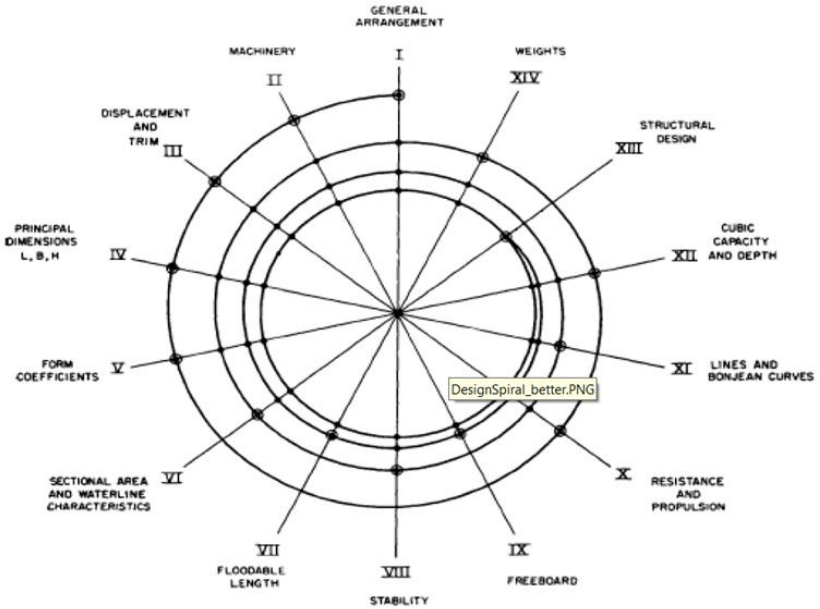
1. Establish the design space and sub-divide along areas of expertise: concurrent subsystem evaluation
2. Gradually and deliberately reduce the design space by integrating preferred sub-spaces: discovery by elimination

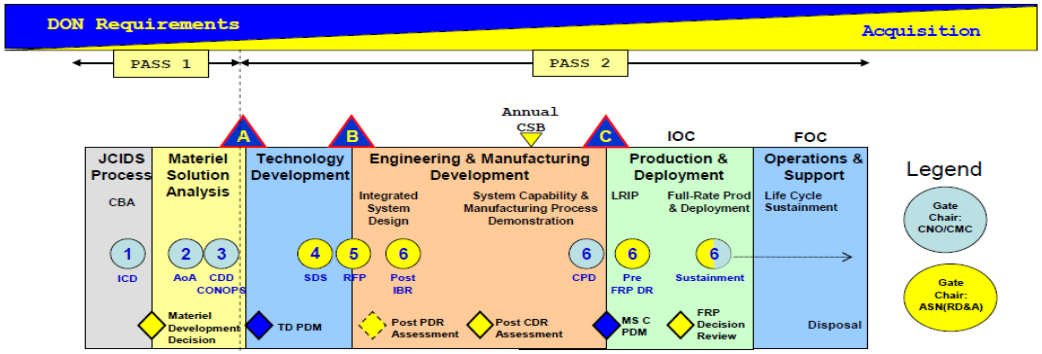


# Prevailing ship acquisition process is point-based

- Traditional ship design process is inherently linear point-based design
- Associated acquisition processes/milestones are also linear point-based design

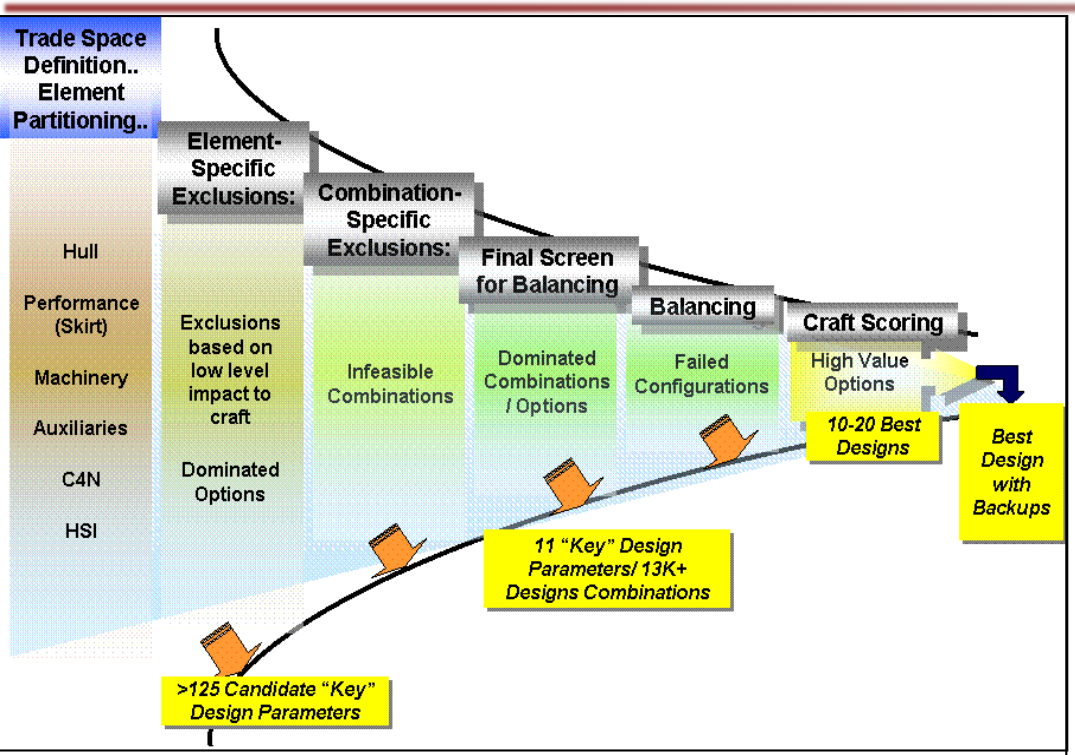




# SBD example 1: Ship-to-Shore Connector




## Benefits

- USN confidence in SBD approach
- Smooth subsequent design reviews

Use SBD to generate CDD

(1) Six partitions, did not know interactions
  - Identified "negotiating relationships" as inter-system variables.

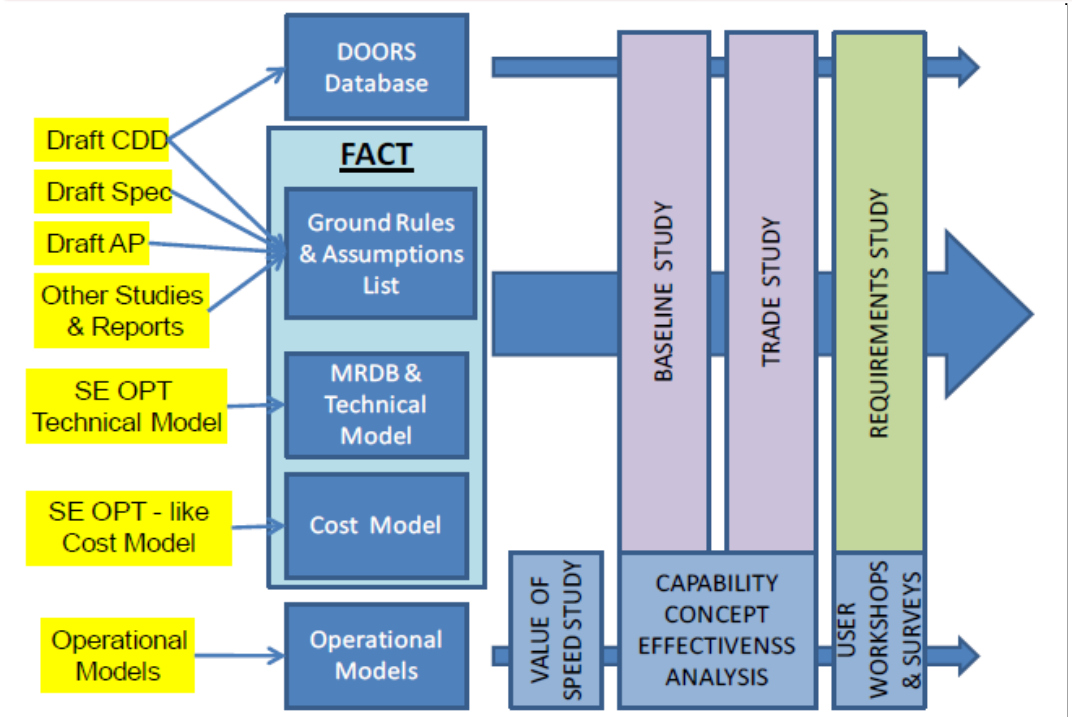
(2) Single integration event
  - 1st pass feasibility check.
  - Balance Loop with LCAC software.
  - Knowledge captured in Trade Space Summaries

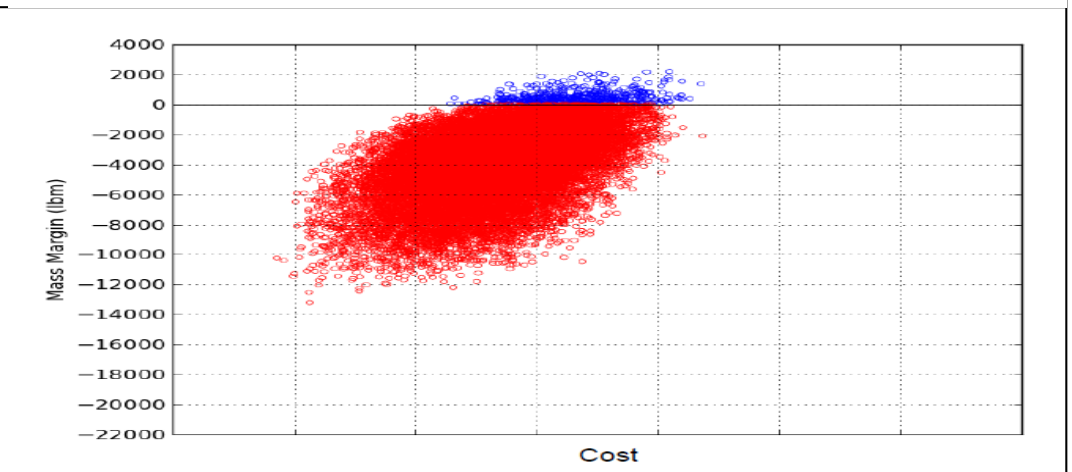
(3) Synthesis provided quantitative metrics for performance evaluation.



# SBD example 2: Amphibious Combat Vehicle




Design Space Exploration to assess cost of High Water Speed vs. Low Water Speed ACV, post-AoA.

(1) Requirements, Database, and Cost teams.

(2) Requirements communicated with Database via MRDB. Cost lagged.

(3) Synthesis software to assess performance.

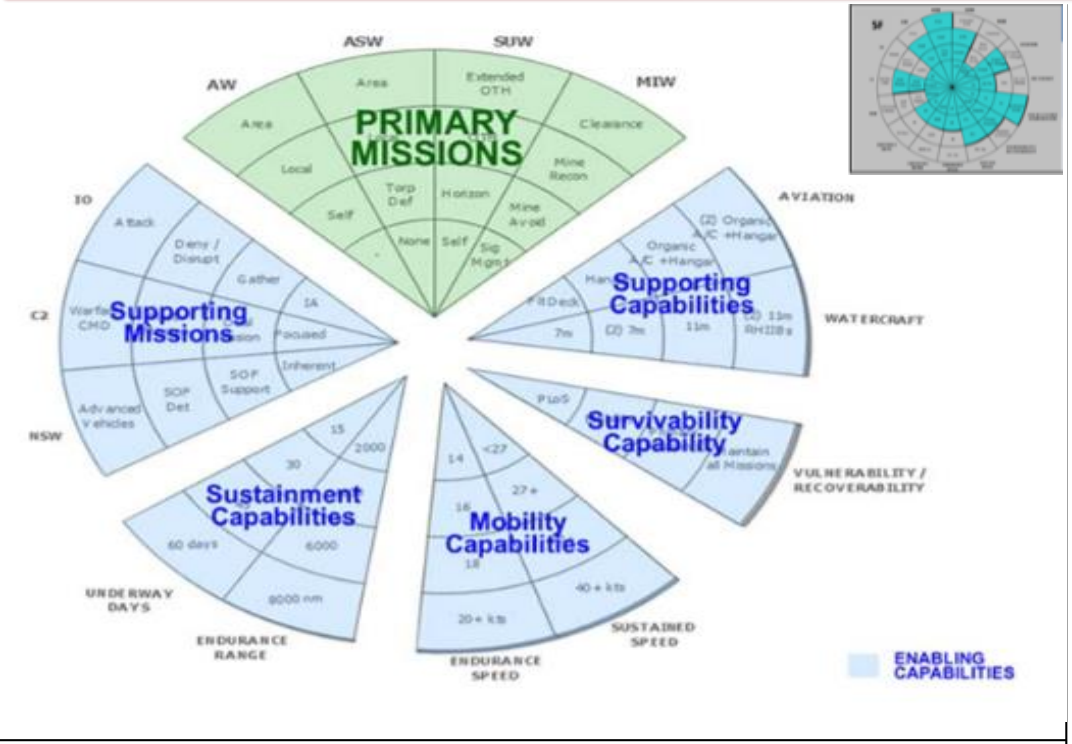
## Benefits

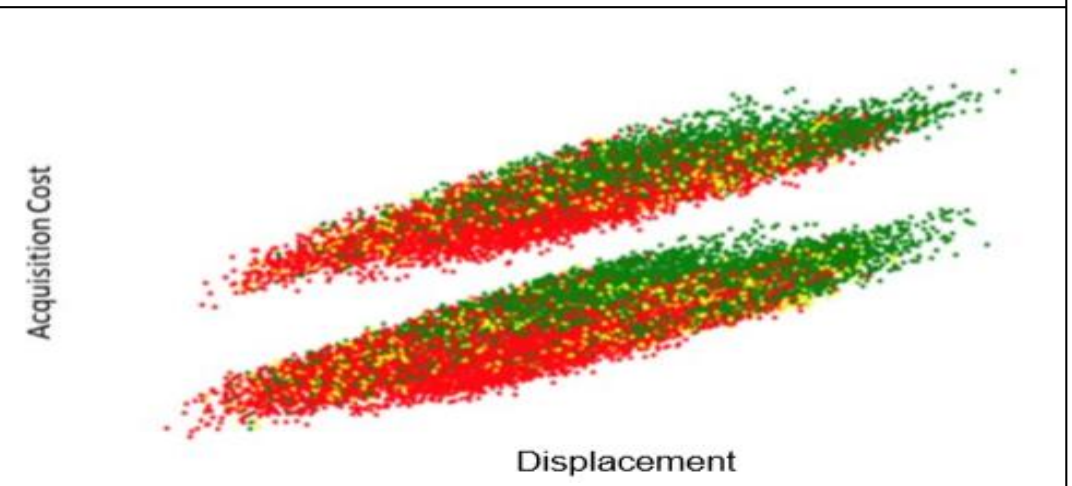
- Decision-makers preferred trade-off decision data presentation.
- SBD "elimination" technique useful to communicate cost vs. capability

## Avoided "..what about this?"

# SBD example 3: Small Surface Combatant Task Force




Quickly assess replacement options for remaining LCS hulls.

(1) Independent HM&E and Combat System teams

(2) Communicated Space, Weight, Power, and Cooling (SWAP-C) through RSDE and ASSET

(3) Used ASSET and RSDE to generate quantitate measures for evaluation.

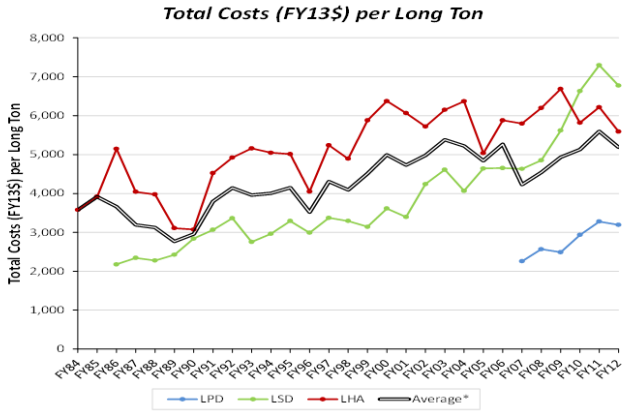
## Benefits

- Stakeholders prefer trade space data presentation technique
- Cost Diversity introduced.
- Ship design tools facilitate SBD principles.

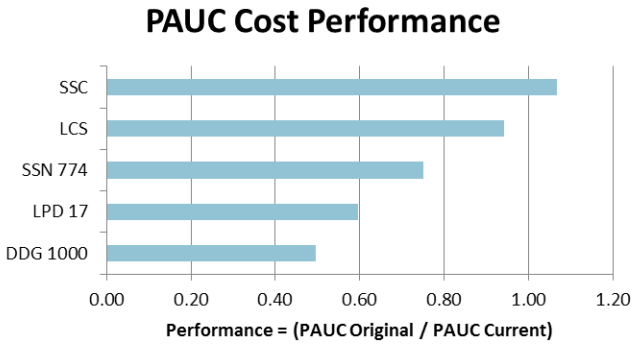
 

# Performance results of SBD approach in the USN

- LPD-17 (1996): First use of IPPD/CE. (Detailed Design)
  - Lowest O&S = ↓ TOC.




- SSC (2008): First use of SBD. (Pre-PD)
  - Best acquisition cost performance.
  - ↓ TOC is expected.

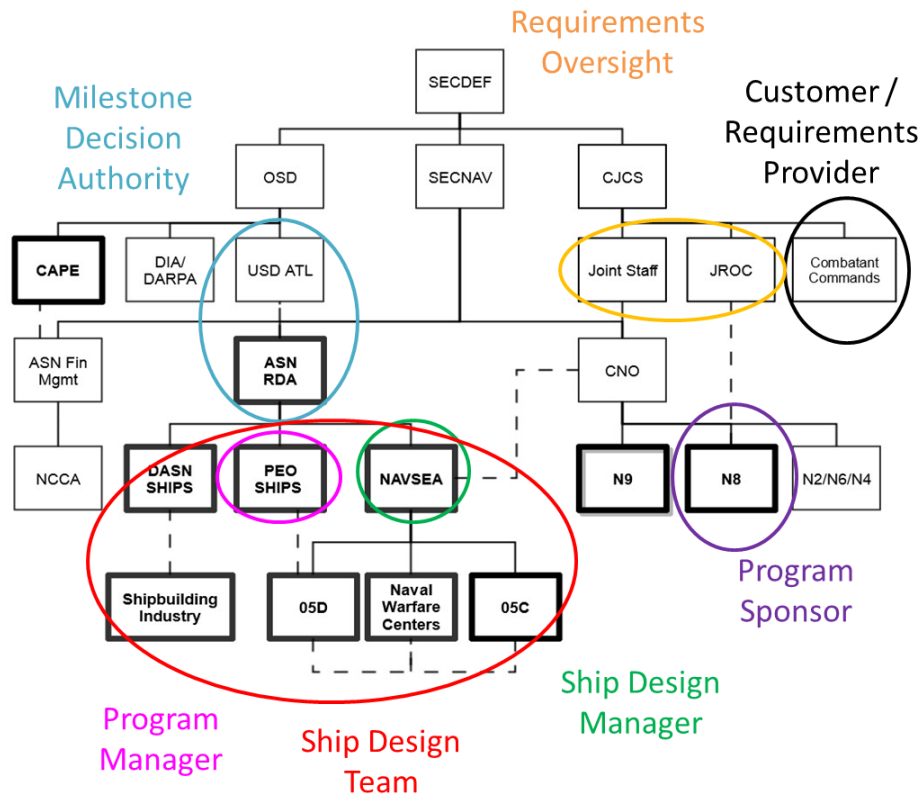



- NSWC CD ERS study (Gray, et al, 2017) found that SBD "process ultimately produced superior design"

# SBD and the 2 Pass/6 Gate acquisition process

*Ship Design Organizations*




**Interviewed**

| Gate | What | Type | Who | Priorities from Interviews |
|---|---|---|---|---|
| 1 | CBA & ICD | Exploratory & Pre-AoA | N8 | Understand intelligence and technology risk |
| | | | | Don't jump to conclusions |
| 2 | AoA | AoA | CNO | Large span of AoA variants |
| | | | | Cost vs. capability trade-off |
| 3 | CDD | Pre-PD | CNO | Feasibility of KPP/KSA performance at cost. |
| 4 | SDS | Preliminary | ASN RDA | Feasibility and cost of sub-system integration. |

## Alignment with SBD

- Gate 2
  - SBD works well with large design space.
- Gate 3
  - SBD proceeds via feasibility assessment

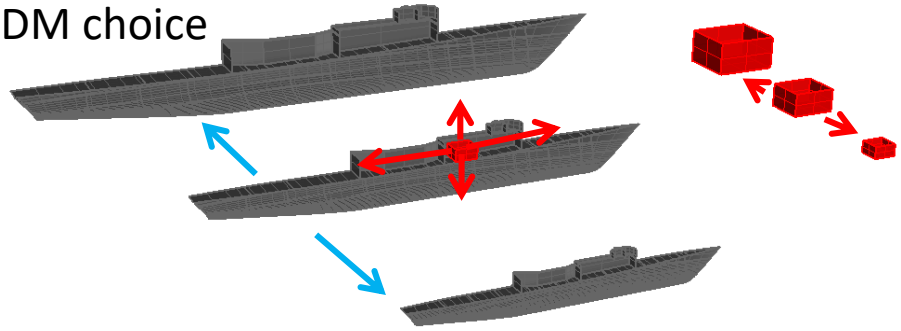
Massachusetts Institute of Technology

# Process Improvement: Gate 2, Analysis of Feasibility (AoF)

Ship Range from regression of SDM choice

Combat System to meet DRM range



| Variants for Trade-off | | CS 1 | CS 2 | CS 3 | CS 4 | CS 5 | CS 6 |
|---|---|---|---|---|---|---|---|
| Hull | Beam : (X ↔ Y) | Variants are either feasible or in-feasible<br><br>Results will produce a "cloud" with a "range" of cost and performance | | | | | |
| | Depth: | | | | | | |
| | Draft: | | | | | | |
| | Cp: | | | | | | |
| Propulsion | Type 1 | | | | | | |
| | Type 2 | | | | | | |
| | Type 3 | | | | | | |
| Energy | Type 1 | | | | | | |
| | Type 2 | | | | | | |
| | Type 3 | | | | | | |
| Aux | Type 1 | | | | | | |
| | Type 2 | | | | | | |
| Crew | Option 1 | | | | | | |
| | Option 2 | | | | | | |
| | Option 3 | | | | | | |

(1) Split design into Combat System and Ship areas
  - Communicate via SWAP-C and LCG/VCG

(2) Use RSDE to input wide CS range into Ship areas for ASSET.
  - Integrate after CS resolved architectures.

## ADVANTAGES

- Parallel effort by Ship and CS = ↓ Design Time and Cost
- More data provides statistical Capability vs Cost trade-off.

# Process Improvement: Gate 3, cont. AoF

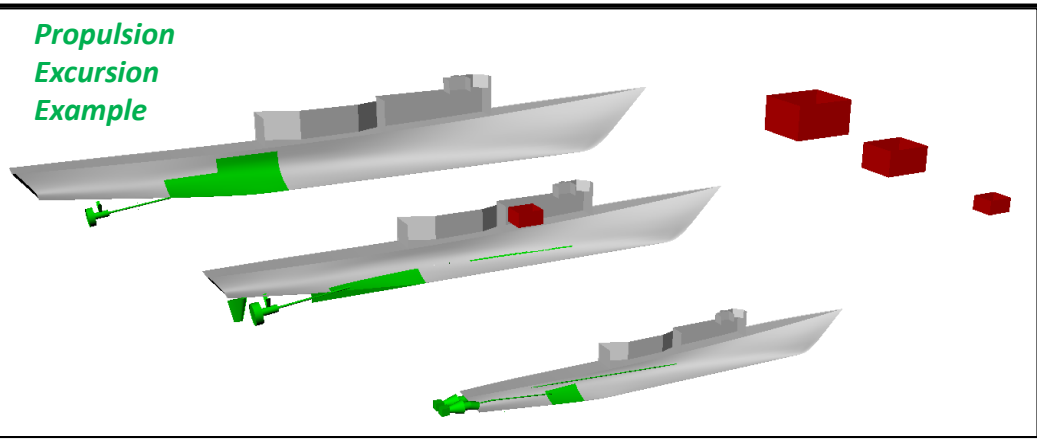
- Feasibility of KPPs/KSAs maintained.
- Build on previous design phase effort.

**Gate 3 SBD Process**

1) Continue Ship / Combat team segregation
2) Sub-system experts study configurations to identify preferred architectures.
3) Communicate preferred configurations through SWAP-C. Eliminate dominated designs.

Continue process until all areas have technical rigor to support CDD.

| Variants for Trade-off | | | CS 1 | CS 2 | CS 3 | CS 4 |
|---|---|---|---|---|---|---|
| Hull | | | | | | |
| Propulsion | Type 1 | Option 1 | Evaluate for dominance | | | |
| | | Option 2 | | | | |
| | | Option 3 | | | | |
| | Type 2 | | | | | |
| | Type 3 | | | | | |





# Conclusions

- Findings on USN use of SBD:
  - Less cost to design, build, and maintain the product—early but encouraging
  - Reduction of design cycle time—seen in all cases
  - Better design knowledge capture—but early still for some cases
- Navy is moving toward more widespread use of set–based design
  - Pushing into new application domains (e.g., from classic design to CDD, trade studies)
  - Evolution of hybrid approaches employing different design strategies (combining SBD with e.g., tradespace exploration methods)
- 2P/6G process can accommodate SBD (up to a point), but can be improved to benefit more from the additional information provided by SBD
  - Multiple decision-makers in acquisition process—all need to be socialized to the value of SBD analysis and presentation of findings
- Implications for formal ship acquisition process in the USN:
  - Analysis of Feasibility as a way to challenge existing acquisition mindsets to encourage greater exploration of the design tradespace
  - Create a temporary TWH position for design process to champion SBD until all SDMs/SIMs have gained familiarity with the process?