Applying Principles of Set-Based Design to Improve Ship Acquisition

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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
**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.

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**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

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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
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.

Benefits
• USN confidence in SBD approach
• Smooth subsequent design reviews
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.

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 quantitative measures for evaluation.

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

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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”
Alignment with SBD

- Gate 2
  - SBD works well with large design space.

- Gate 3
  - SBD proceeds via feasibility assessment.
Process Improvement: Gate 2, Analysis of Feasibility (AoF)

Ship Range from regression of SDM choice

Combat System to meet DRM range

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<thead>
<tr>
<th>Variants for Trade-off</th>
<th>CS 1</th>
<th>CS 2</th>
<th>CS 3</th>
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Variants are either feasible or in-feasible

Results will produce a “cloud” with a “range” of cost and performance

(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.

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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.

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Evaluate for dominance

Propulsion Excursion Example

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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?