Measuring Diversity in Set-Based Design

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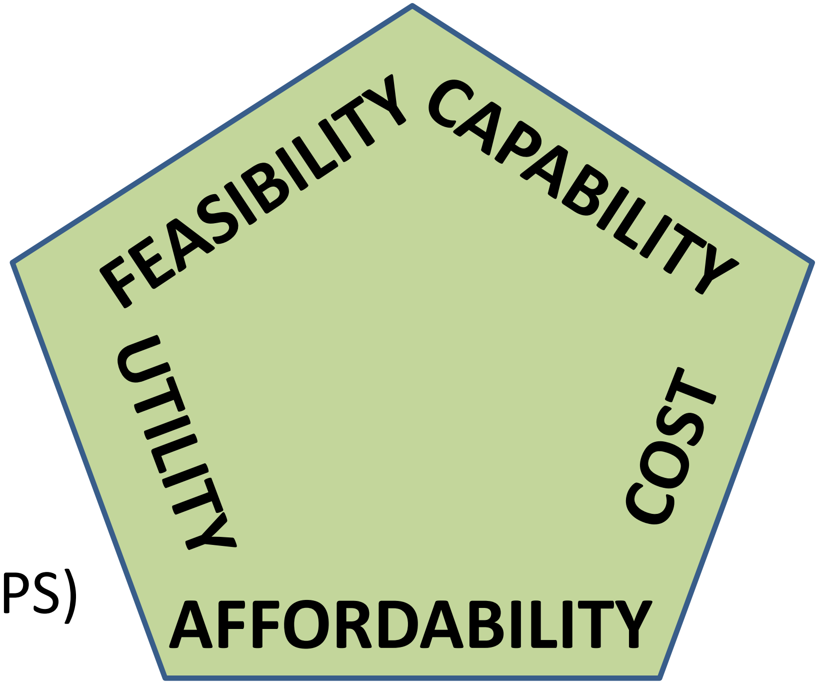
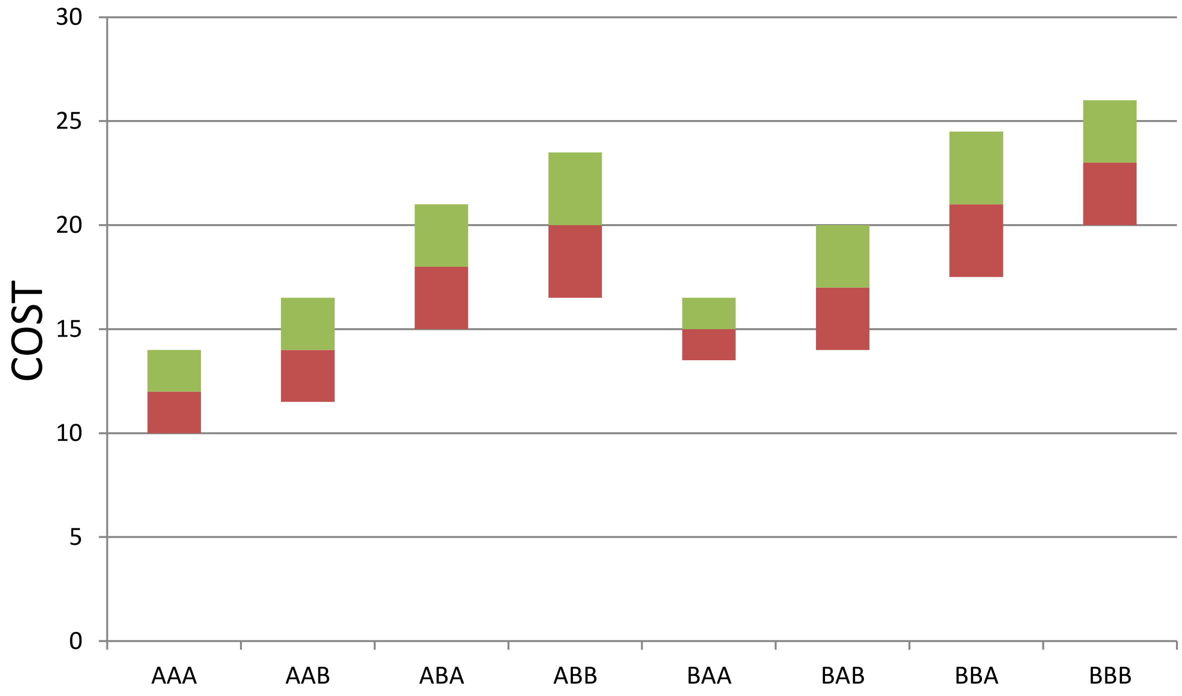
Concept Studies

- Understand the interaction of
  - **Cost**
  - **Capability**
  - **Feasibility**
  - Utility
  - Affordability
- Capability Concept
  - Set of requirements
  - Concept of Operations (CONOPS)
  - Employment strategy
  - Acquisition strategy
  - Support strategy

Focus of this Presentation (Cost, Capability, Feasibility)



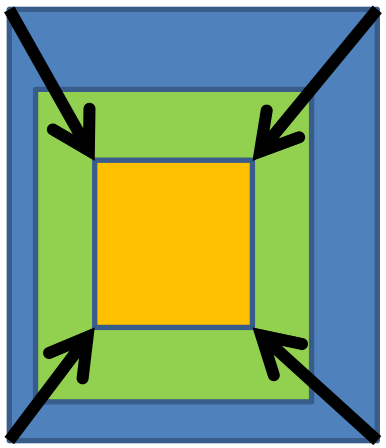
Comparing Capability Concept Cost



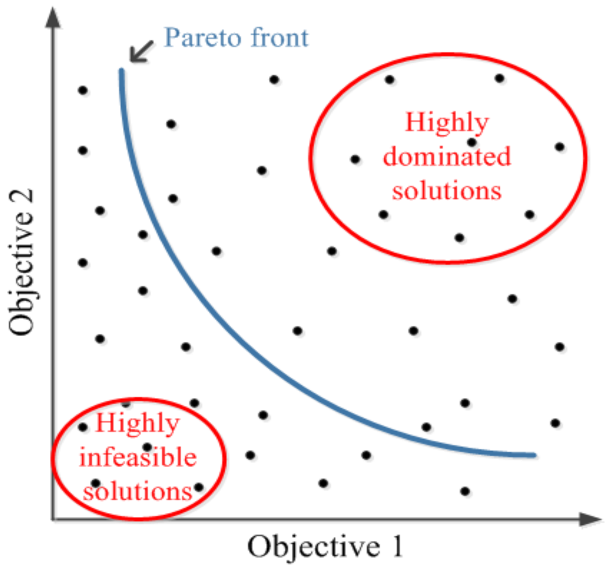
Compare ranges of cost

Cost Ranges account for uncertainty in technical solution (set of feasible points) and Cost Estimating Relationship (CER) uncertainty

Set Based Design



- Consider sets of configurations (Design Space) rather than point designs for each Capability Concept
  - If there is one feasible configuration, then there are likely many feasible configurations for a given Capability Concept
- Design Decisions eliminate regions of the design space, not pick solutions
  - Eliminate regions where a feasible solution is unlikely or …
  - Eliminate regions that are Pareto Dominated, and remaining region still has sufficient diversity
- Make decisions at the Capability Concept level and not on specific point designs – Don't decide too soon!
  - Employ properties of the set of feasible configurations



McKenney, Thomas, and David Singer, "Set-Based Design," SNAME (mt) Marine Technology, July 2014, pp. 51-55.

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Viability vs Feasibility

- Definitions
  - Feasibility: A configuration meets stated requirements based on analysis conducted to date
  - Viability: A configuration meets stated requirements when placed in service
- Feasibility does not always imply Viability this early in the development process
  - Some performance areas not assessed
  - Modeling not always indicative of real world
- Many feasible configurations with sufficient diversity imply viability
  - Chances of all feasible configurations not being viable probably low …
  - If a Set Based Design Approach is used
- A configuration that is not feasible is probably not viable either

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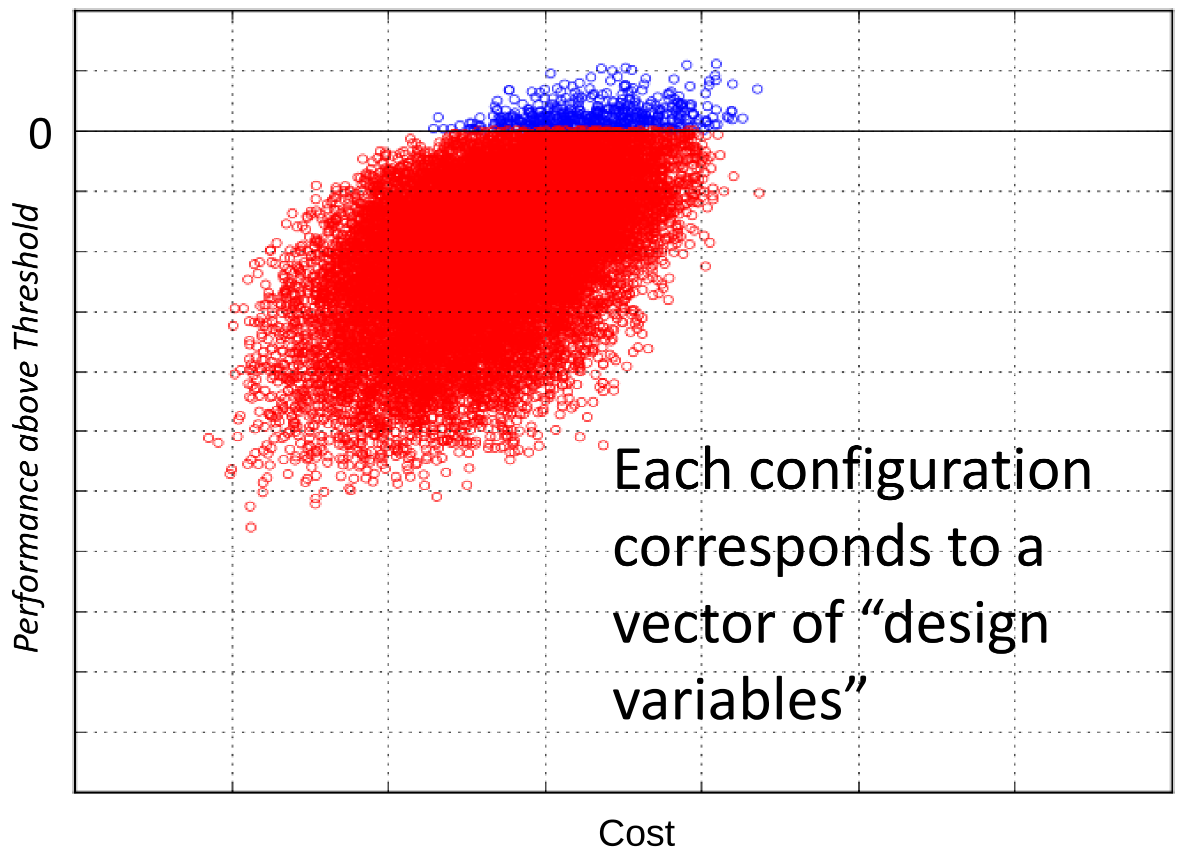
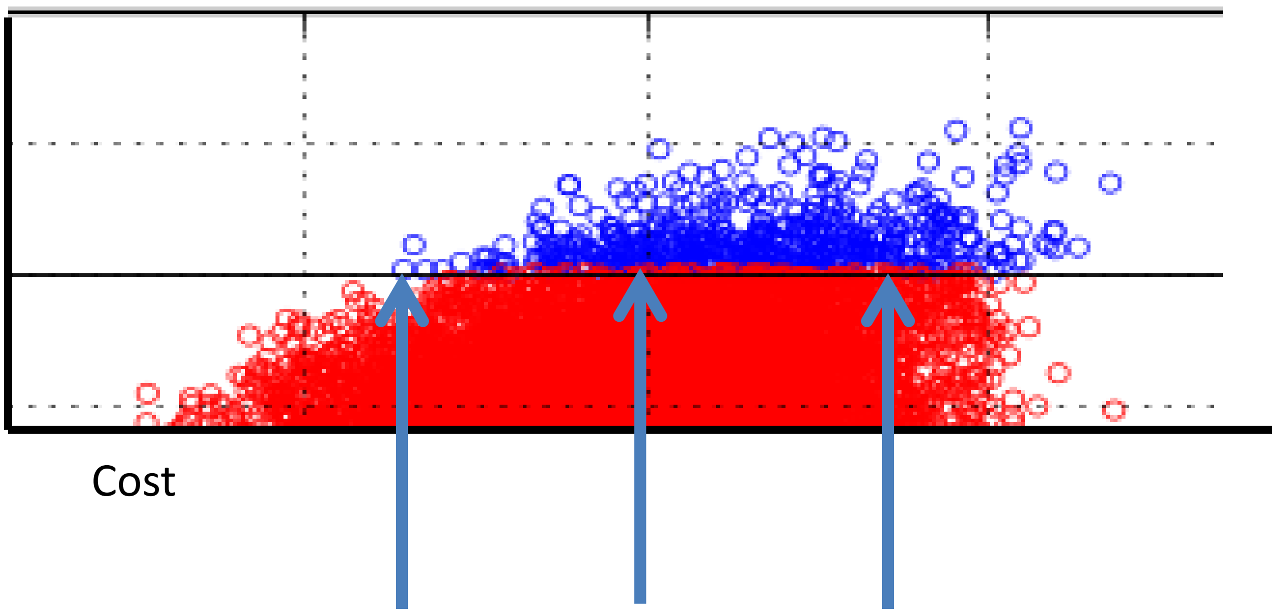
Scatter Plot of Configurations for a specific Capability Concept



What is a good representative cost?

Answer: The lowest cost for which the risk that all feasible configurations with a lower or equal cost are not viable is low. The risk is evaluated via a Diversity Metric



If this configuration is Viable, then this is the ideal representative cost

Many configuration options for this cost

Even more configuration options for this cost

Diversity Metric

- Measures how different the feasible configurations within a set of configurations are from each other
  - Higher diversity implies that the chance that all feasible configurations are not viable is lower
- Based on a set of "Diversity Variables"
  - A subset of the "Design Variables"
  - Discrete (at least for now)
  - Aligned with degree of risk
    - Express weight margin as percentage rather than specific value.

Approach

- Identify a subset of the feasible configurations which are the lowest cost, yet are likely to contain at least one viable configuration.
  - For each diversity variable, identify the number of options that must be represented in the subset (MIN_NBR_OPTIONS)
  - For each of the MIN_NBR_OPTIONS options for the diversity variable, the subset must have a minimum of MIN_NBR_CONFIGS_PER_OPTION configurations.

Approach (continued)

- Calculate BASE_SUM which is the sum of the product of MIN_NBR_OPTIONS and MIN_NBR_CONFIGS_PER_OPTION for all the diversity variables
- Order all of the feasible configurations from lowest cost to highest cost
- For each configuration and each diversity variable, construct an array of the diversity variable options and the number of times that option exists in the configuration and all lower cost configurations.
- Calculate DV_NBR_METRIC by selecting the MIN_NBR_OPTIONS array elements with the highest numbers and adding together the minimum of MIN_NBR_CONFIGS_PER_OPTION and the array element value.
- The DIVERSITY_SCORE is the sum of DV_NBR_METRIC for all the diversity variables.
- The DIVERSITY_METRIC is the DIVERSITY_SCORE divided by the BASE_SUM.
  - The lowest value is for the lowest cost configuration and is equal to the number of diversity variables divided by BASE_SUM
  - DIVERSITY_METRIC monotonically increases in ascending order of cost
  - The maximum value is 1.0.

Translating the Diversity Metric into a Representative Cost

- Direct Assessment
  - Use the cost for the configuration with specific diversity metrics to establish a range. (e.g. 0.75 and 1.00)
- Indirect Assessment
  - Create a subset of the feasible configurations by only including those with component options that first meet the MIN_NBR_OPTIONS and MIN_NBR_CONFIGS_PER_OPTION.
  - Use the mean and standard deviation of the costs for this subset.

Simple Example

CONFIG_ID	COMPONENT A	COMPONENT B	COMPONENT C	COST
1	A1	B1	C1	111
2	A1	B2	C1	121
3	A2	B1	C1	211
4	A2	B2	C1	221
5	A3	B1	C1	311
6	A3	B2	C1	321
7	A1	B1	C2	112
8	A1	B2	C2	122
9	A2	B1	C2	212
10	A2	B2	C2	222
11	A3	B1	C2	312
12	A3	B2	C2	322
13	A1	B1	C3	113
14	A1	B2	C3	123
15	A2	B1	C3	213
16	A2	B2	C3	223
17	A3	B1	C3	313
18	A3	B2	C3	323
19	A1	B1	C4	114
20	A1	B2	C4	124
21	A2	B1	C4	214
22	A2	B2	C4	224
23	A3	B1	C4	314
24	A3	B2	C4	324

Simple Example (cont)

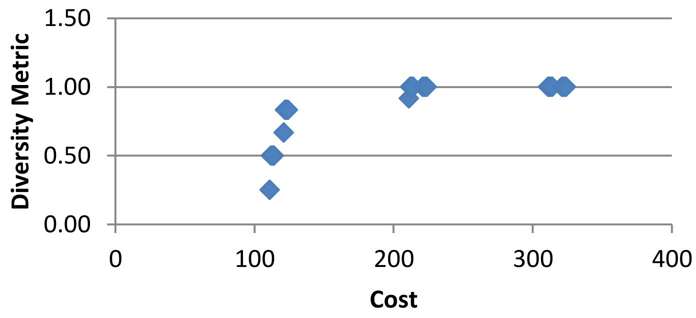
CONFIG_ID	COMPONENT A	COMPONENT B	COMPONENT C	COST	Diversity Metric
1	A1	B1	C1	111	0.25
7	A1	B1	C2	112	0.50
13	A1	B1	C3	113	0.50
19	A1	B1	C4	114	0.50
2	A1	B2	C1	121	0.67
8	A1	B2	C2	122	0.83
14	A1	B2	C3	123	0.83
20	A1	B2	C4	124	0.83
3	A2	B1	C1	211	0.92
9	A2	B1	C2	212	1.00
15	A2	B1	C3	213	1.00
21	A2	B1	C4	214	1.00
4	A2	B2	C1	221	1.00
10	A2	B2	C2	222	1.00
16	A2	B2	C3	223	1.00
22	A2	B2	C4	224	1.00
5	A3	B1	C1	311	1.00
11	A3	B1	C2	312	1.00
17	A3	B1	C3	313	1.00
23	A3	B1	C4	314	1.00
6	A3	B2	C1	321	1.00
12	A3	B2	C2	322	1.00
18	A3	B2	C3	323	1.00
24	A3	B2	C4	324	1.00

For each Component:
MIN_NBR_OPTIONS = 2
MIN_NBR_CONFIGS_PER_OPTION = 2

BASE_SUM = 12

Direct Method Range

Diversity Metric vs Cost



Simple Example (Indirect Method)

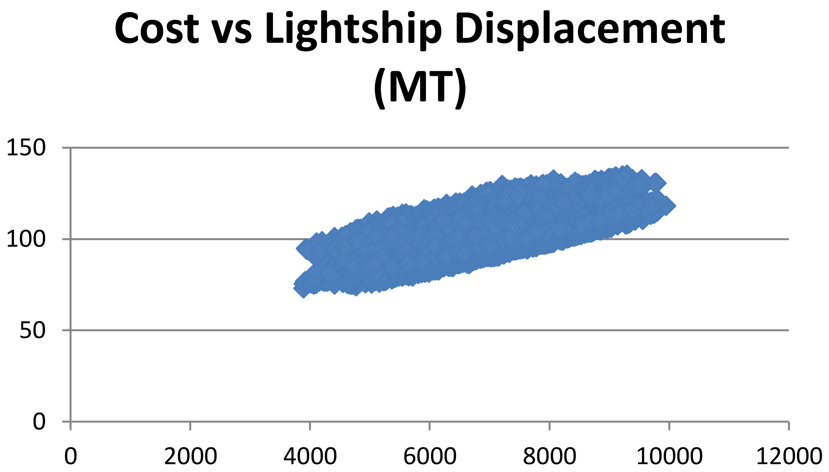
CONFIG_ID	COMPONENT A	COMPONENT B	COMPONENT C	COST	Diversity Metric
1	A1	B1	C1	111	0.25
7	A1	B1	C2	112	0.50
2	A1	B2	C1	121	0.67
8	A1	B2	C2	122	0.83
3	A2	B1	C1	211	0.92
9	A2	B1	C2	212	1.00
4	A2	B2	C1	221	1.00
10	A2	B2	C2	222	1.00

Mean Cost = 166.5
Standard Deviation of Cost = 53.7

Discard configurations with A3, C3, and C4

Ship Design Example

- Dataset of 51,000 Feasible Configurations
- 164 Configurations needed to achieve a diversity metric of 1.0
- Direct Assessment cost [76.6 ,78.6]
- Indirect Assessment
  - Included 3352 configurations
  - Average Cost = 90.4
  - Std Deviation = 6.7



Diversity Variable	Total Number of Options	MIN_NBR_OPTIONS	MIN_NBR_CONFIGS_PER_OPTION
Propulsion Architecture	5	4	10
Weight Equation	2	2	10
Main Engine Power	6	3	10
Hogging Constant	2	2	10
Deckhouse Material	2	2	10
AAW suite	8	3	10
ASW suite	6	3	10
SUW suite	7	3	10

Ship Design Example (cont)

Diversity Variable	Number of Configurations to meet criteria
AAW suite	40
SUW suite	43
ASW suite	51
Weight Equation	54
Deckhouse Material	57
Propulsion Architecture	119
Main Engine Power	153
Hogging Constant	164

COST DRIVERS:
Concentrate near term design activity on understanding these options

Summary

- Base cost estimates for capability concepts on a set of feasible configurations
- The set should incorporate sufficient diversity to minimize the probability that all the configurations in the set prove to be not viable.
- A method has been demonstrated for calculating diversity and two approaches presented for developing a representative cost.