Program and Portfolio Tradeoffs Under Uncertainty Using Epoch-Era Analysis

A Case Application to Carrier Strike Group Design

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Presentation Outline

- The Challenge of Design Under Uncertainty
- Strategies for Considering Uncertainty
  - Epoch-Era Analysis (EEA)
  - Modern Portfolio Theory (MPT)
- Joint EEA and MPT Method for Affordability
- Case Application: Carrier Strike Group (CSG)

THE CHALLENGE OF DESIGN UNDER UNCERTAINTY

Design for Value Sustainment

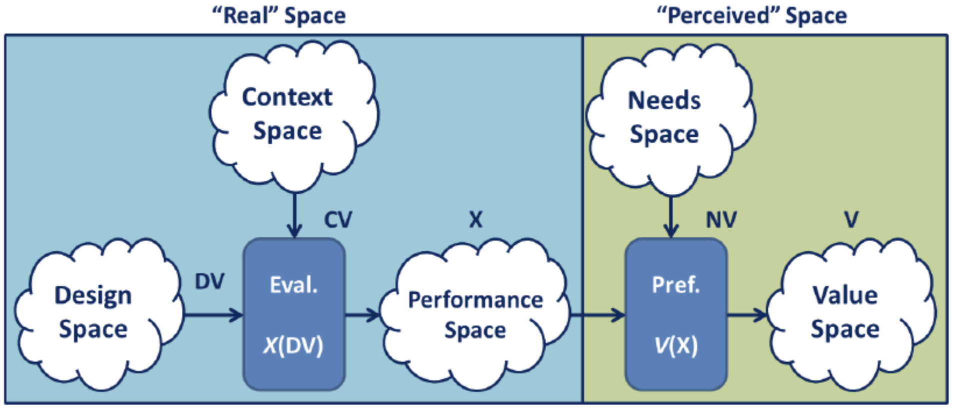
The modern warfighter operates in a global environment that will inevitably experience dramatic, dynamic shifts in context

Exogenous uncertainties exist in the acquisition and operational environment

- Emerging technologies (e.g., UAS maturation)
- Political transition (e.g., low carbon fuels mandate)
- Economic shifts (e.g., global recession)
- Resource availability (e.g., rare-earths crisis)

Stakeholder needs may vary with the decision context

- Change of stakeholder *preferences*
- Change of mission *objectives*



(Beesemyer, 2012)

Design for value sustainment assesses system performance in a variety of foreseeable contexts and needs during conceptual design

SEAri
Systems Engineering Advancement Research Initiative

Design for Affordability

- 74 Nunn-McCurdy cost breeches between 1997 and 2011
- Numerous breeches corresponded to context changes in the environment of the acquisition programs(GAO, 2011)
- A variety of system-design methodologies have been developed in response to the Better Buying Power (BBP) mandates(Carter, 2010)

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Can systems engineering principles create sustained lifecycle *affordability* for engineering portfolios?

Design Abstraction Terminology

Acquisition and development efforts face different challenges and opportunities contingent on the scope of the design abstraction

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System-Level: a singular major architectural element

Program-Level: multiple elements fulfilling common capability requirements

Portfolio-Level: multiple elements that collectively fulfill a set of joint capabilities

Portfolio-Level Design

System-level methodologies do not effectively enable the design of specific portfolio-level properties

- Multi-system acquisition and operation of portfolios presents higher order complexities not addressed by system-level design techniques
- DoD standards for SoS design are described in the *Systems Engineering Guide for System-of-Systems* (2008)
- Some methods have also been adapted for portfolio design
  - Portfolio Theory application for SoS decision making (Davendralingam et. al, 2011)
  - Real options analysis for IT SoS acquisition strategies (Komoroski et. al, 2006)
  - Tradespace-based affordability analysis for complex systems (Wu et.al, 2014)

Portfolio design for lifecycle value-sustainment is a difficult challenge requiring advanced systems engineering approaches

STRATEGIES FOR CONSIDERING UNCERTAINTY

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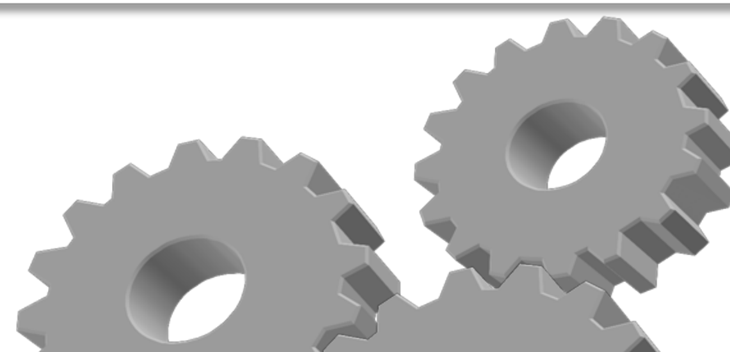
Modern Portfolio Theory (MPT) for Engineering Portfolios



Consistencies

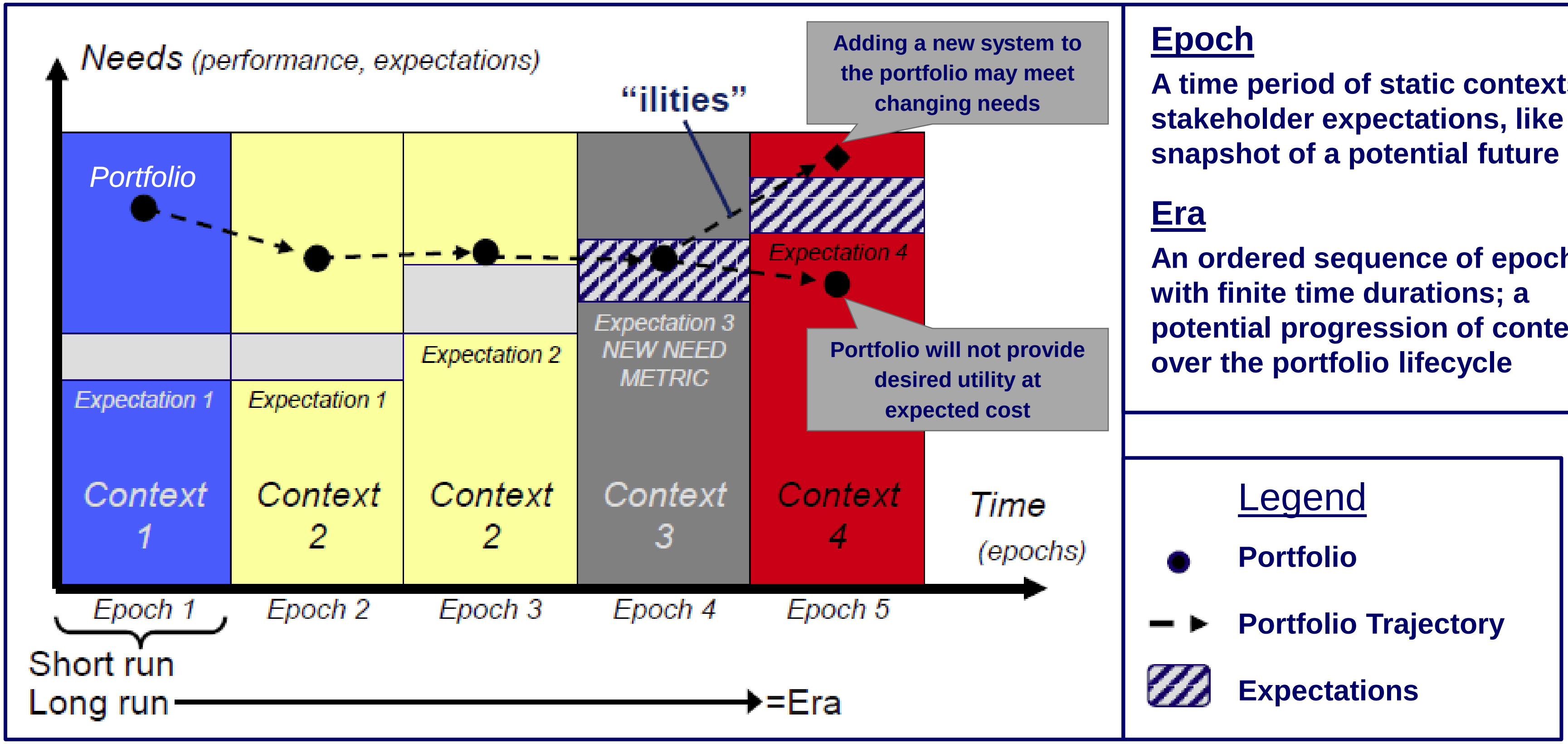
- Value elicitation from stakeholders
- Modeling of asset value
- Founded in utility theory
- Identifies “efficient frontier” of potential alternatives

Differences

- Asset performance is non-Gaussian
- Portfolio value is dictated by non-linear asset performance aggregation
- Covariance is insufficient to describe asset correlation
- Asset availability is dynamic
- Costs may accompany diversification

Select elements of Modern Portfolio Theory can improve the design and acquisition of engineering systems portfolios

Epoch-Era Analysis



Epoch

A time period of static contexts and stakeholder expectations, like a snapshot of a potential future

Era

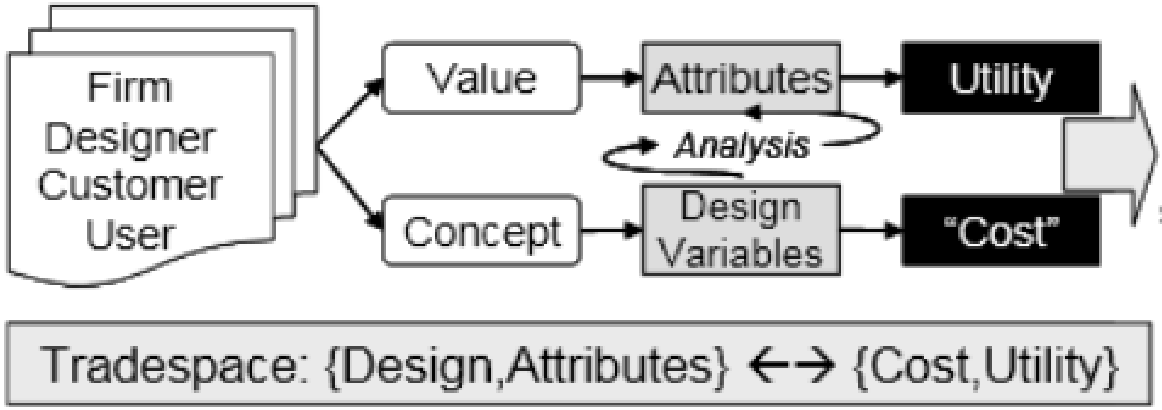
An ordered sequence of epochs with finite time durations; a potential progression of contexts over the portfolio lifecycle

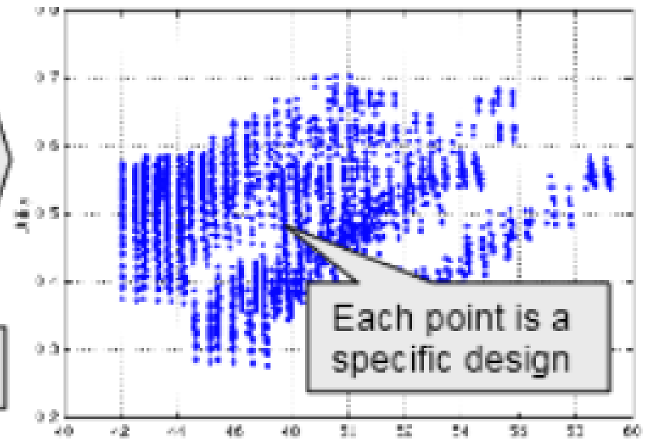
(Ross & Rhodes, 2008)

EEA provides a method to compare potential portfolio performance with respect to the dynamic environment in which they operate

Multi-Attribute Tradespace Exploration

- Engineering portfolio design has traditionally revolved around Analysis of Alternatives studies concerning a few promising point designs
- Multi-Attribute Tradespace Exploration (MATE) enables designers to consider a far greater set of alternatives for affordability (Wu et.al, 2014)

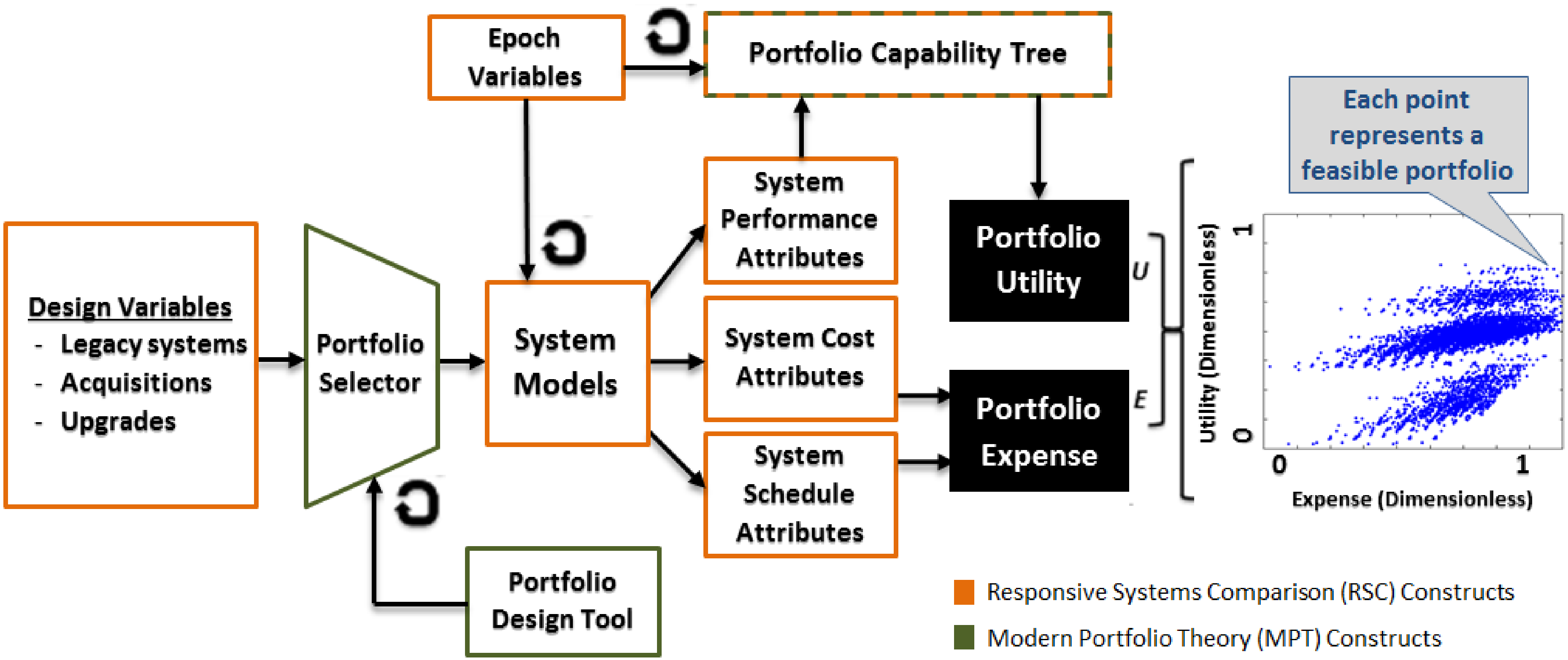




The combination of MPT, EEA, and MATE provides new capability for portfolio-level design for lifecycle affordability

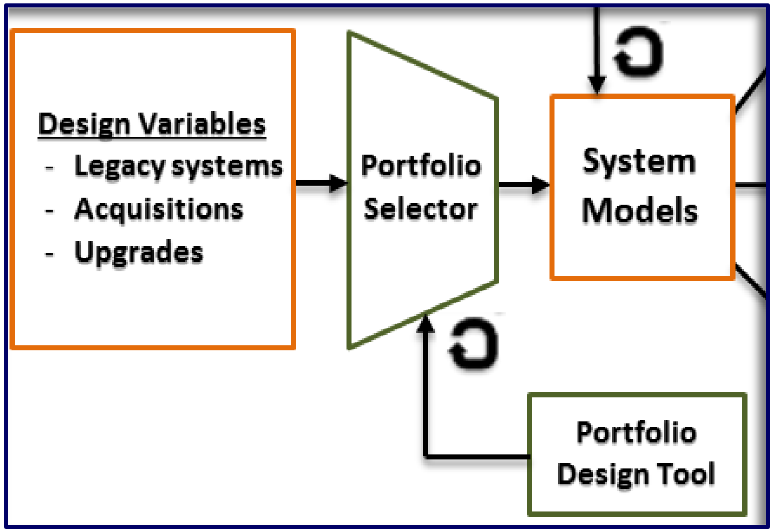
JOINT EEA AND MPT METHOD TO SUPPORT DESIGN FOR AFFORDABILITY

Portfolio-Level Epoch-Era Analysis for Affordability (PLEEAA)



Fuses elements of MPT with EEA through the framework of MATE

Portfolio Enumeration



Portfolio Design Tool

- Conducts asset allocation
- Applies portfolio class constraints
- Enumerates all possible portfolios

Portfolio Selector

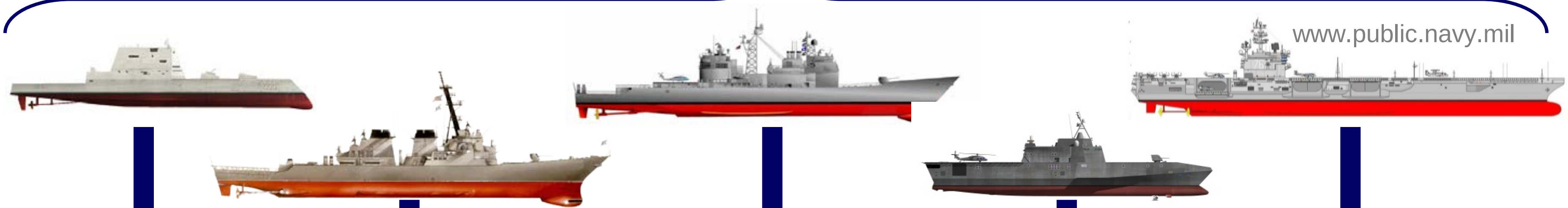
- Compiles a specific portfolio for modeling

An engineering portfolio may be represented by three primary design variables

- Legacy Systems – existing hardware available to the portfolio
- Acquisitions – new assets produced for the portfolio
- Upgrades – change options available for legacy systems

Portfolio Design Tool

Fundamental to MPT, asset allocation identifies potential classes of assets which may constitute portfolio elements



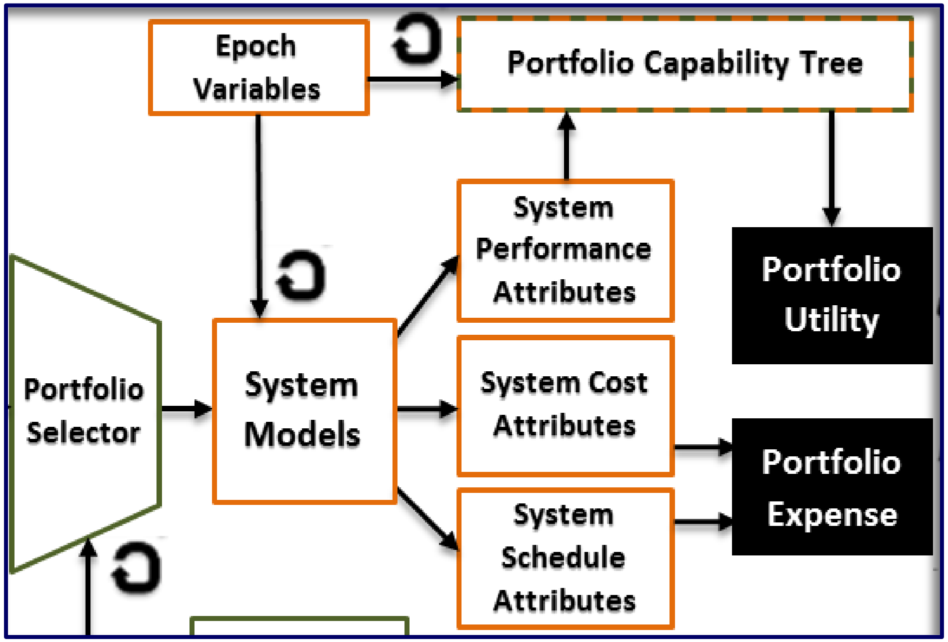
0 to 3 | 0 to 5 | 0 to 1 | 0 to 5 | 1

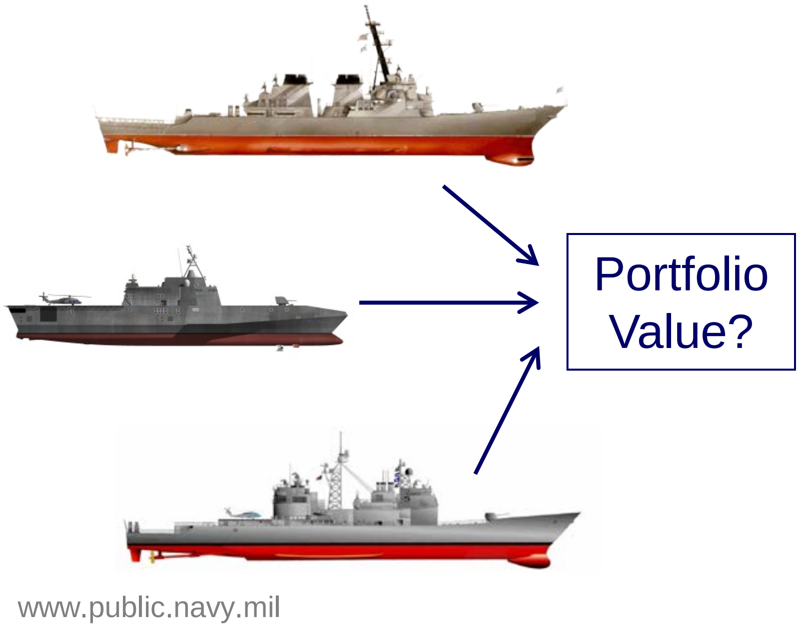
At least 2

Class constraints set specific rules for each asset class (similar to finance investment thresholds)

- Min/Max # of assets
- Min/Max cost of asset

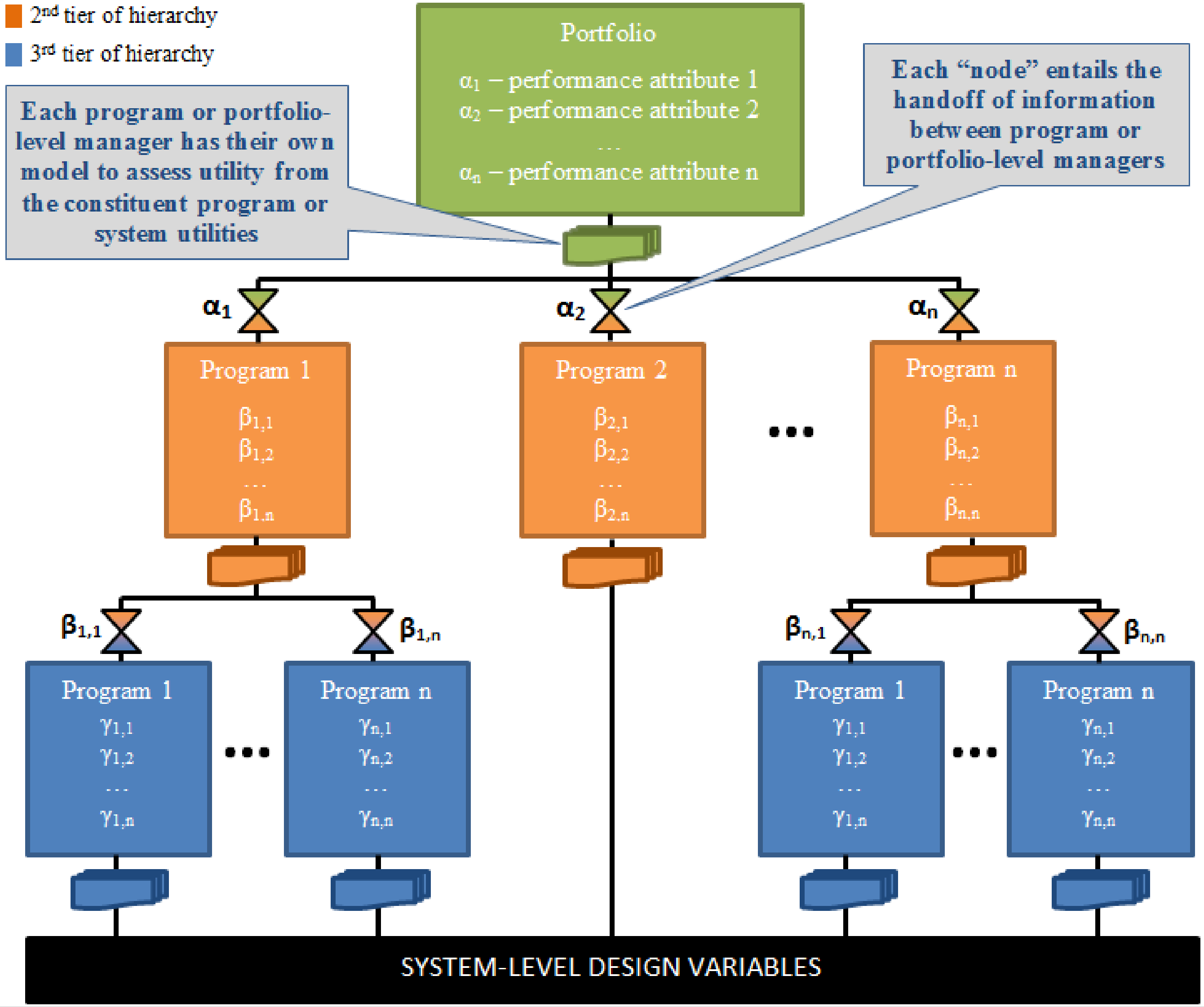
Constituent System Modeling





- System-level cost attributes are directly aggregated to portfolio expense
- The capability tree is a capability-based value mapping to aggregate system performance to determine portfolio utility

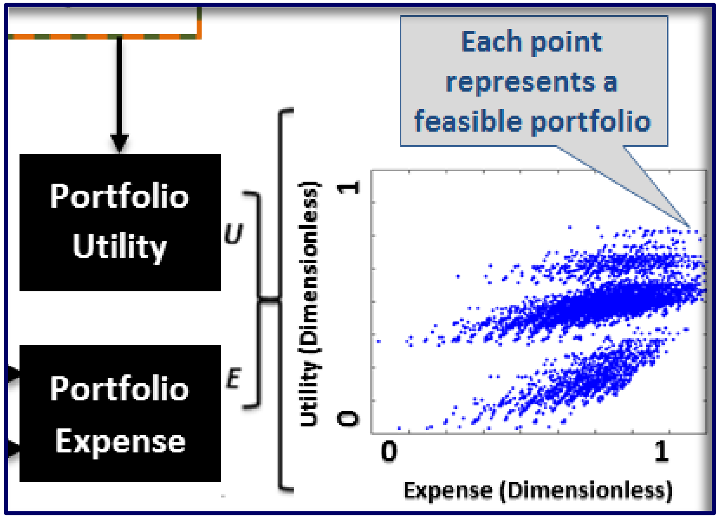
Portfolio Capability Tree



Supports top-down transfer of needs and bottom-up aggregation of performance

Enables the consideration of complementary and substitute system impacts

MATE with Epoch-Era Analysis



Tradespace of Portfolios

- Utility and Expense axes
- Multi-attribute utility theory used to describe value of portfolio performance
- Hundreds of thousands of portfolios may be visualized

EEA provides several techniques to analyze the promising portfolio designs

- Single-Epoch Analysis: identification of "promising" portfolios in isolated epochs
- Multi-Epoch Analysis: exploration of the influence of contextual uncertainty on a set of promising portfolios
- Single-Era Analysis: identification of time-dependency of promising portfolio value delivery through multiple epochs
- Multi-Era Analysis: exploration of path-dependency of promising portfolio value delivery through multiple epochs

CASE APPLICATION:
CARRIER STRIKE GROUP (CSG)

Portfolio-Level Context Definition and Design Formulation

Identify the basic problem statement and design space for the proposed portfolio

VALUE PROPOSITION

"responsive, flexible capability for sustained maritime power projection and combat survivability to shape the operation environment, respond to crisis, and protect the US and allied interest in any threat environment" – Chief of Naval Operations (2010)

PERFORMANCE ATTRIBUTES

1. Electronic warfare capability
2. Defensive capability
3. Offensive capability
4. Power projection
5. Logistics

Primary portfolio stakeholders

- Combatant commander (CCDR)
- Operational commander

EXPENSE ATTRIBUTES

1. Acquisition cost
2. Influence cost
3. Operations cost
4. Schedule cost

Potential Constituent Systems

Legacy Systems
Arleigh Burke Flight I
Arleigh Burke Flight II
Arleigh Burke Flight IIA
Ticonderoga

Legacy Systems
Nimitz with Complement
Los Angles
Virginia
Supply Class

Acquisitions
Next Generation Combat Ship (NGCS) – 6 variants
Arleigh Burke Flight IIA Restart
Arleigh Burke Flight III
Zumwalt

Upgrades
Arleigh Burke Flight I upgrade
Arleigh Burke Flight II upgrade

CSG Capability Tree Formulation

Levels of capability tree hierarchy
Portfolio Level Capability Attributes
2nd Level SoS Capability Attributes
3rd Level SoS Capability Attributes
# of System Level Performance Attributes

Levels of capability tree hierarchy

Portfolio Level	2nd Level SoS	3rd Level SoS	# of System Level Performance Attributes
CSG Electronic Warfare Capability	Early Warning		6
	Weapon system detection		6
	Electromagnetic System		5
CSG Defensive Capability	Battlespace Defense Capability	Sea superiority	5
		Air Superiority	5
		Undersea Superiority	5
		Combat Search and Rescue	2
	Naval Asset Defense Capability	Anti-Ship Missile Defense	5
		Anti-Ship Kinetic Weapon	5
		Sea Mine Defense	5
		Torpedo Defense	5
		Crew Defense	4
CSG Offensive Capability	Naval Gun Fire Support		5
	Missile Strike Capability	Ballistic Missile Interception	5
		Cruise Missile Strike	5
	Torpedo Capability		5
	Sea Basing Capability		3
	Special Forces Insertion		4
Power Projection			2
CSG Logistics			4

Branch of capability tree (applies to the CSG Electronic Warfare Capability rows)

CSG Epoch Characterization

Seven epoch variables identified yielding a total of 2187 distinct epochs

EV Category	Epoch Variable	[Range]	Units
EV – Technology	Advanced Energy Weapons (AEW)	[0, 5, 40]	MW
EV – Technology	Unmanned Aerial Systems (UAS)	[0, 2, 5]	Berths
EV – Maintenance	Overhaul Event Costs	[0, 0.5e9, 2e9]	Billions $
EV – Policy	Budget	[80, 100, 150]	%
EV – SoS management	Cooperation Costs	[80, 100, 150]	%
EV – Threats	Enemy Threat	[Low, Med, High]	Level
EV – Threats	Asymmetric Threat	[Low, Med, High]	Level

Five epochs initially selected for demonstration through the Carrier Strike Group case study

Epoch Names	*Epoch Variables*						
	AEW	**UAS**	**Overhaul**	**Budget**	**Cooperation**	**Enemy**	**Asymmetric**
Baseline	0	0	0	100	100	Low	Med
Small Navy	0	2	0	80	150	Low	Low
War on Terror	5	5	0	100	80	Low	High
Major Conflict	40	5	0	150	80	High	Med
Peacekeeping	5	0	0.5e9	100	100	Med	Med

Design-Epoch-Era Tradespace Evaluation

- Based upon the 19 potential constituent systems
  - 53,108,336 unique portfolios were enumerated
  - 524,160 portfolios were evaluated
  - Between 220 and 477,916 portfolios were valid, depending upon the epoch

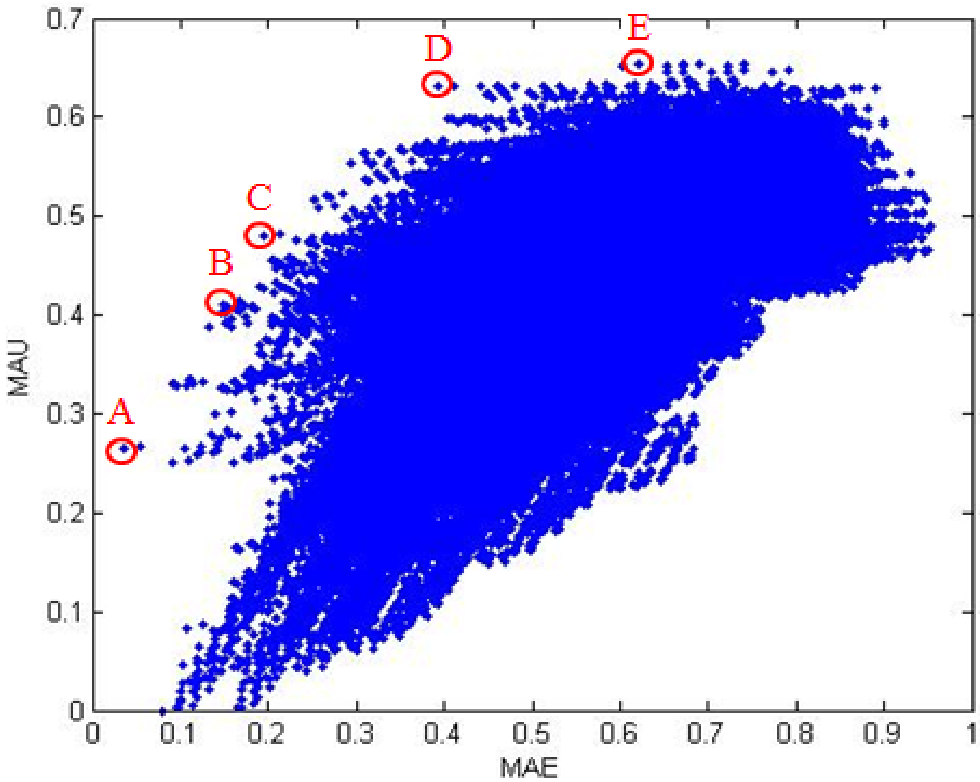
Epoch	Valid Portfolios	Yield
Baseline	173,581	33.1%
Small Navy	220	0.04%
War on Terror	140,398	26.8%
Major Conflict	477,916	91.2%
Peacekeeping	191,558	36.5%

Severely limiting epoch due to a 20% budget cut and 50% rise in cooperation costs

The PLEEAA method enables a designer to consider far more alternatives, each in numerous potential future scenarios

Single-Epoch Analysis

Tradespace Exploration is conducted independently in each epoch

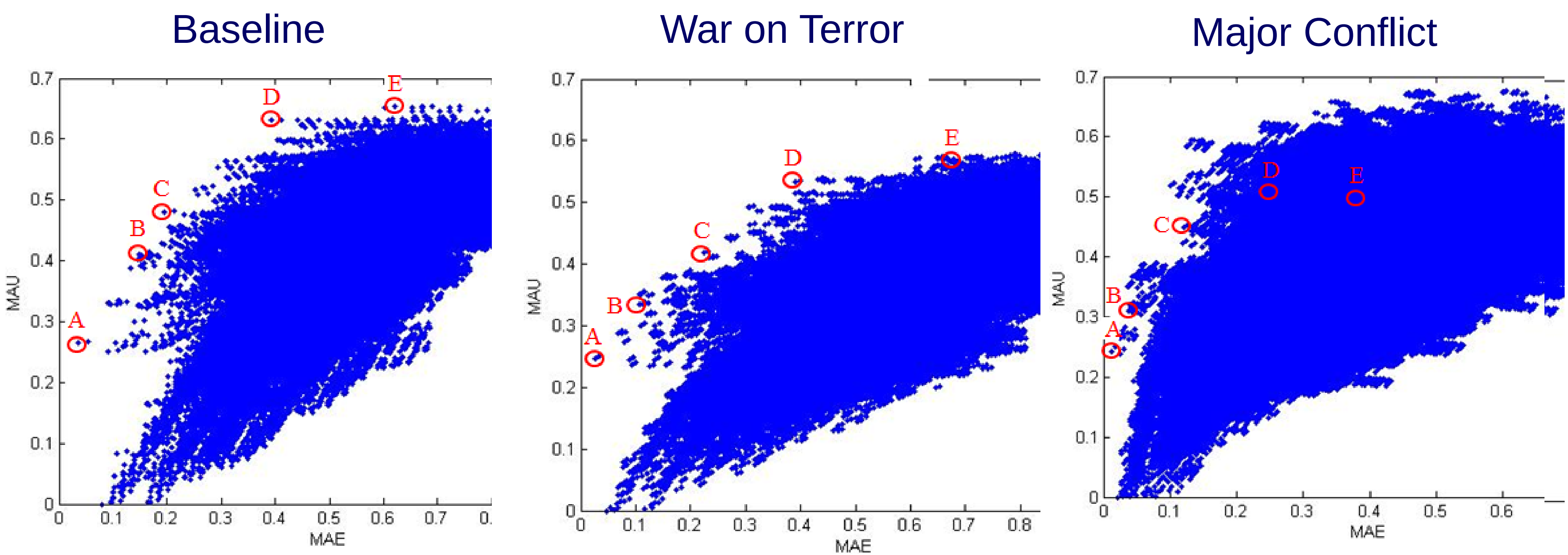


#	MAU	MAE	Portfolio Composition
A	0.2651	0.0352	1 Arleigh Burke Flight III 1 Nimitz with Complement 1 Los Angles
B	0.4109	0.1487	1 Arleigh Burke Flight I 1 Arleigh Burke Flight II 1 Arleigh Burke Flight III 1 Nimitz with Complement 1 Los Angles
C	0.4800	0.1953	2 Arleigh Burke Flight III 1 Nimitz with Complement 1 Los Angles
D	0.6305	0.3920	2 Arleigh B. Flight II Upgrade 2 Arleigh Burke Flight III 1 Nimitz with Complement 1 Los Angles
E	0.6532	0.6206	2 NGCS Variant 6 2 Arleigh B. Flight II Upgrade 2 Arleigh Burke Flight III 1 Nimitz with Complement 1 Virginia

Promising portfolios are identified on the Pareto frontier of each epoch

Multi-Epoch Analysis

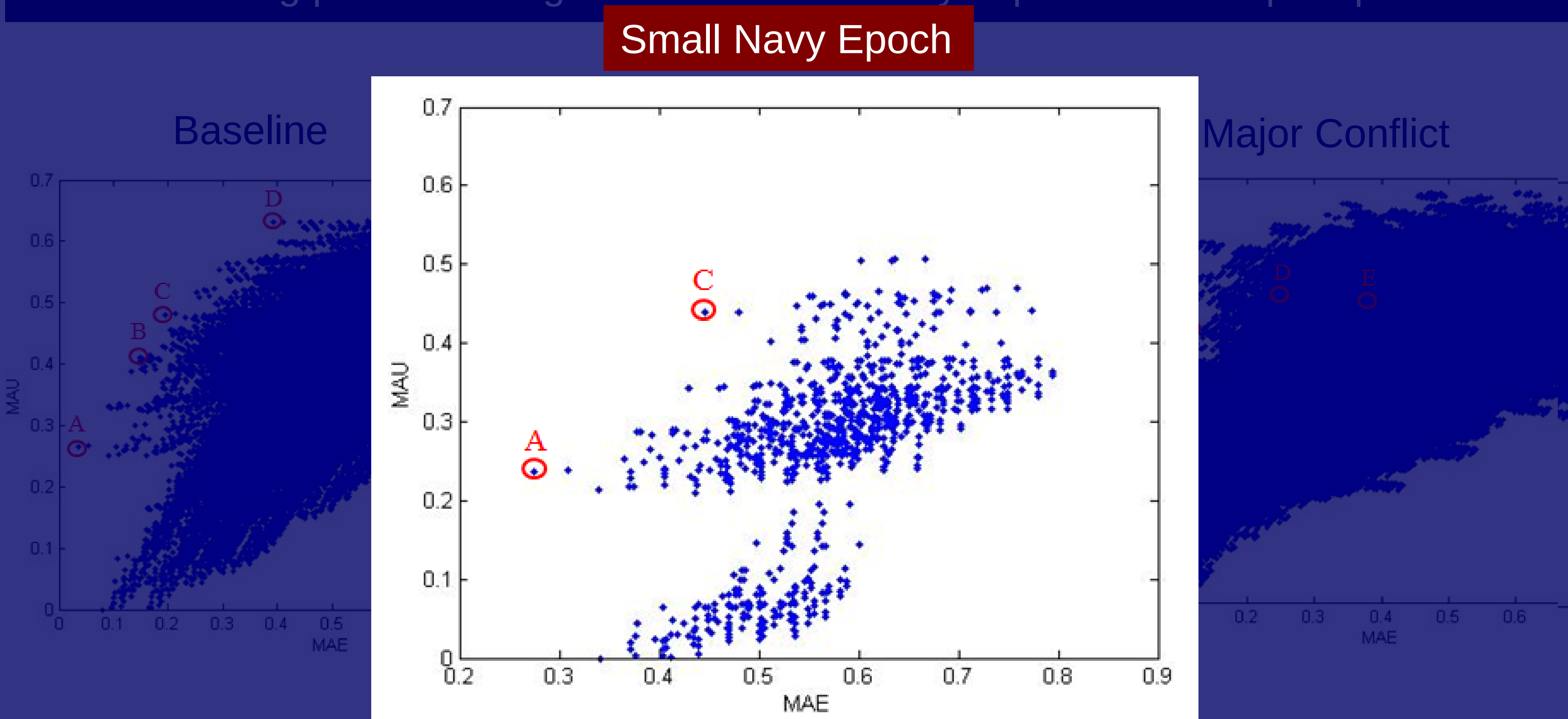
Promising portfolio designs are simultaneously explored in multiple epochs



Multi-Epoch analysis illustrates the influence of contextual uncertainty on the utility of potential Carrier Strike Group portfolios

Multi-Epoch Analysis

Promising portfolio designs are simultaneously explored in multiple epochs



Multi-Epoch analysis illustrates the influence of contextual uncertainty on the utility of potential Carrier Strike Group portfolios

CSG Era Construction

- An era is an ordered sequence of epochs
- Evaluating portfolio designs over an era illustrates the potential lifecycle value robustness of the portfolio
- Two eras were constructed from the five epochs through a narrative approach

ERA 1

Baseline (5yr) → War on Terror (5yr) → Peacekeeping (10yr) → Baseline (3yr) → Small Navy (7yr)

TIME →

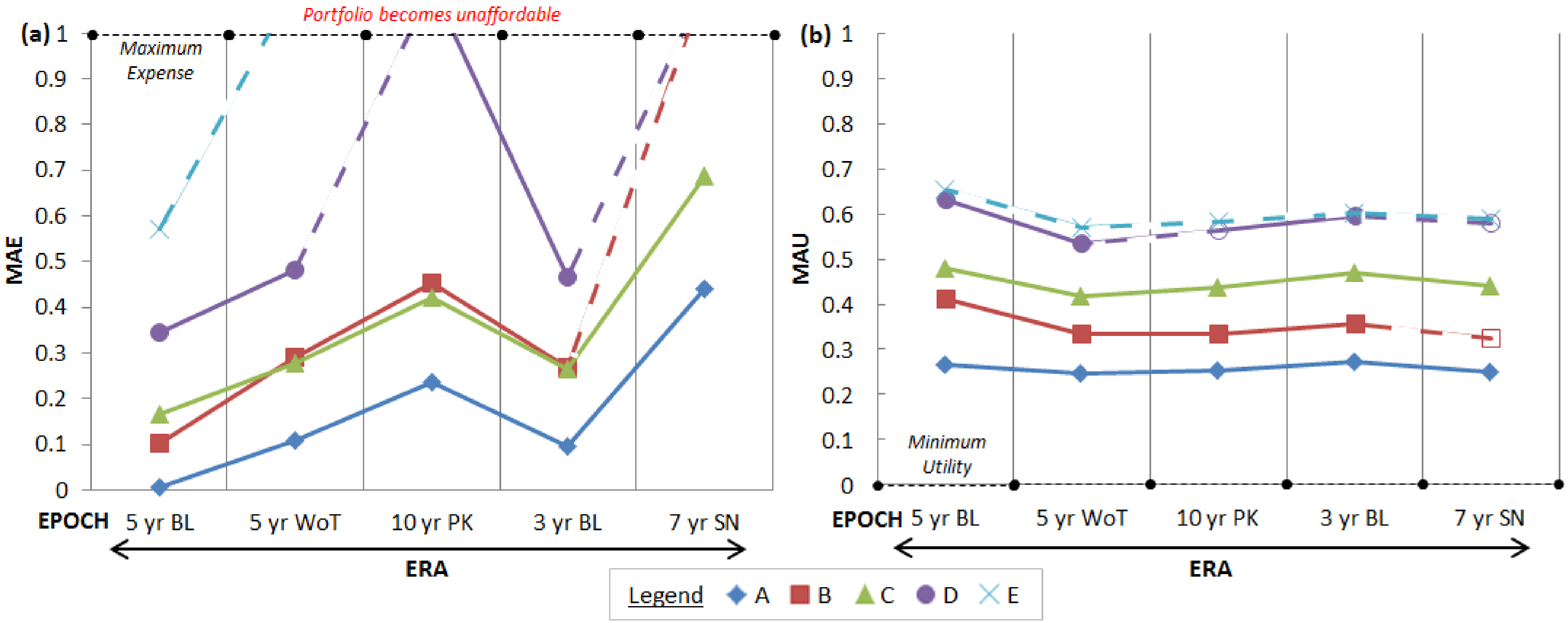
ERA 2

Peacekeep. (5yr) → Small Navy (5yr) → Major Conflict (5yr) → Peacekeep. (12yr) → Baseline (3yr)

Single-Era Analysis

Promising portfolio designs independently explored in the constructed eras

Baseline (5yr) → War on Terror (5yr) → Peacekeeping (10yr) → Baseline (3yr) → Small Navy (7yr)



Single-Era Analysis enables exploration of the time-dependent affordability of promising CSG portfolios in one potential future

Discussion

Can systems engineering principles be applied to create sustained lifecycle *affordability* for engineering portfolios despite changing contexts?

- The PLEEAA method supports design for affordability during conceptual design
  - Considers new contexts before they arrive
  - Assesses the lifecycle value sustainment of potential portfolios
  - Communicates portfolio values to constituent systems
  - Aggregates constituent system performance to portfolio utility
- The case study enables acquisitions officers and designers to explore promising CSG portfolio performance in numerous potential futures

PLEEAA improves the ability of decision makers to design for lifecycle portfolio affordability

Questions?

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SUPPORT/BACKUP SLIDES

System, Program and Portfolio

Acquisition and development efforts face different challenges and opportunities contingent on the scope of the design abstraction

System-Level: Design that is inclusive of a singular major architectural element that is semi-independent from the remainder of the architecture

Program-Level: Design that requires joint consideration of multiple independent or semi-independent constituent elements such that each element fulfills a common set of capability requirements subject to identical stakeholder value metrics

Portfolio-Level: Design that seeks to create a collection of heterogeneous assets, both from legacy and new sources, that can collectively provide a set of emergent capabilities through the aggregate performance of each constituent system

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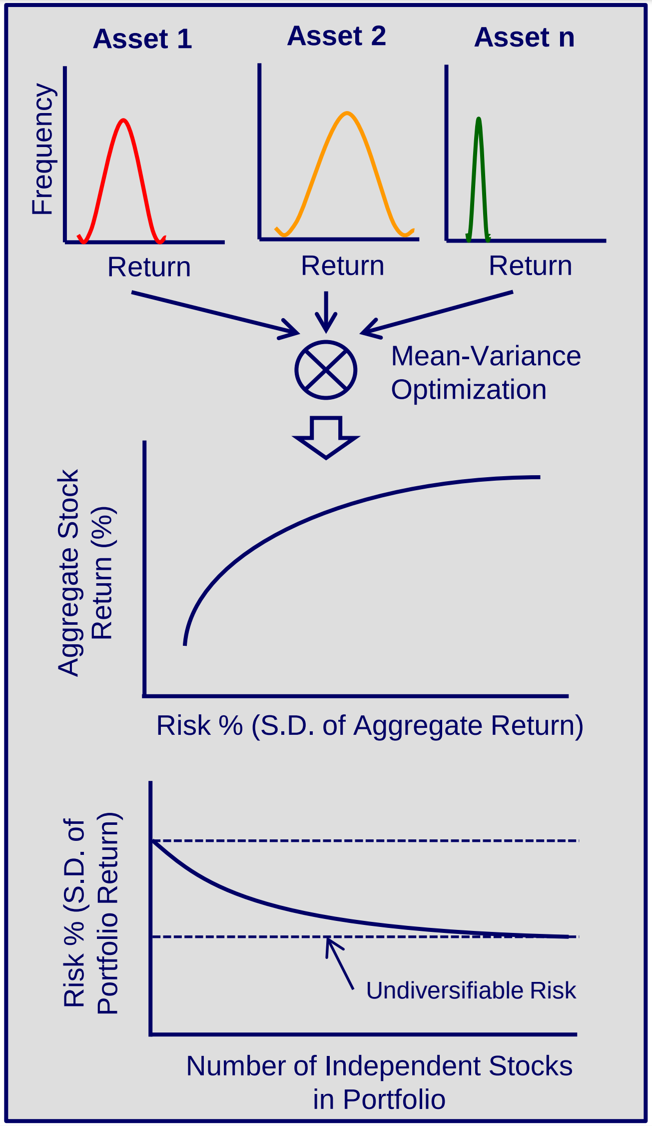
Modern Portfolio Theory

- Utilized by financial institutions and operations research since the 1950's
- Constructs groupings of investments that maximize return (utility) subject to an acceptable threshold of risk (cost)
- Result in an "efficient frontier" of potential investment sets
- Relies upon negative trending covariance in diversified assets to reduce aggregate risk, or Mean-Variance optimization
- A variety of MPT derivatives exist which introduce non-normally distributed risks and semi-variance among assets



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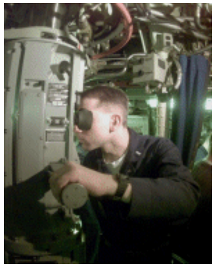
Complementary and Substitute Systems

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Complementary Systems

- Value delivery enhanced in at least one performance attribute
- Gain new capability in a performance attribute
- Often results from a change to the system's CONOPS

Substitute Systems

- Simultaneous, overlapping value delivery in a performance attribute
- Often dependent upon the CONOPS
- Systems may be substitute in one performance attribute, but not necessarily in others

PLEEAA, provides two mechanisms to address complementary and substitute systems through the capability tree architecture

1. SME matching with potential interaction opportunities

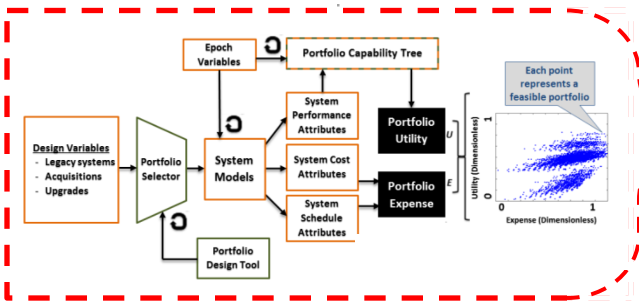
2. Level of Combination Complexity adjustment factors (Chattopadhyay, 2009)

Case Study Application of PLEEAA

Information Gathering

1. Value-Driving Context Definition
2. Portfolio-Level Stakeholder Value-Driven Design Formulation
3. Capability Tree Stakeholder Value-Driven Design Formulation
4. Epoch Characterization
5. System-Level Capability Assessment

Alternatives Evaluation



6. Design-Epoch-Era Tradespace Evaluation

Alternatives Analysis

7. Single Epoch Analysis
8. Multi-Epoch Analysis
9. Era Construction
10. Single-Era Analysis
11. Multi-Era Analysis

Future Work

- The work conducted in this research represent initial efforts to extend EEA to the portfolio-level of design
- Numerous opportunities exist to improve PLEEAA techniques, and add additional capabilities
  - Expanded schedule cost factors
  - Dynamic entry and exit of systems from portfolios
  - More extensive collaboration costs and “likelihood of participation” factors
  - Design for “graceful degradation” capability
  - Expanded mechanism to characterize complementary and substitute systems