SEAri Short Course Series

Course: PI.26s Epoch-based Thinking: Anticipating System and Enterprise Strategies for Dynamic Futures

Lecture: Lecture 9: Formulating Epoch-based Strategies for Technology & Organizations

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Systems Engineering Advancement Research Initiative

[PI.26s] Epoch-Based Thinking: Anticipating System and Enterprise Strategies for Dynamic Futures

Lecture 9
Formulating Epoch-Based Strategies for Technology & Organizations

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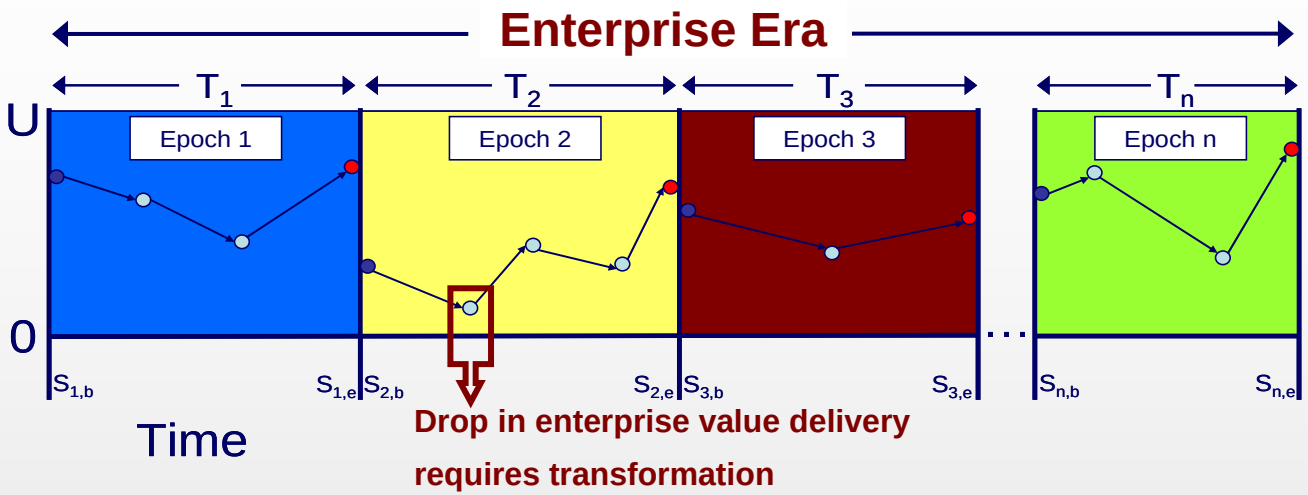
Outline

- Examples of using Epoch-Based Thinking across
  - Enterprises (organization)
  - Systems-of-systems (organization/technology)
  - Off-shore patrol cutter (technology)

Enterprise Value Delivery Across Epoch Shifts

Epoch is a time period for which context and expectations are fixed

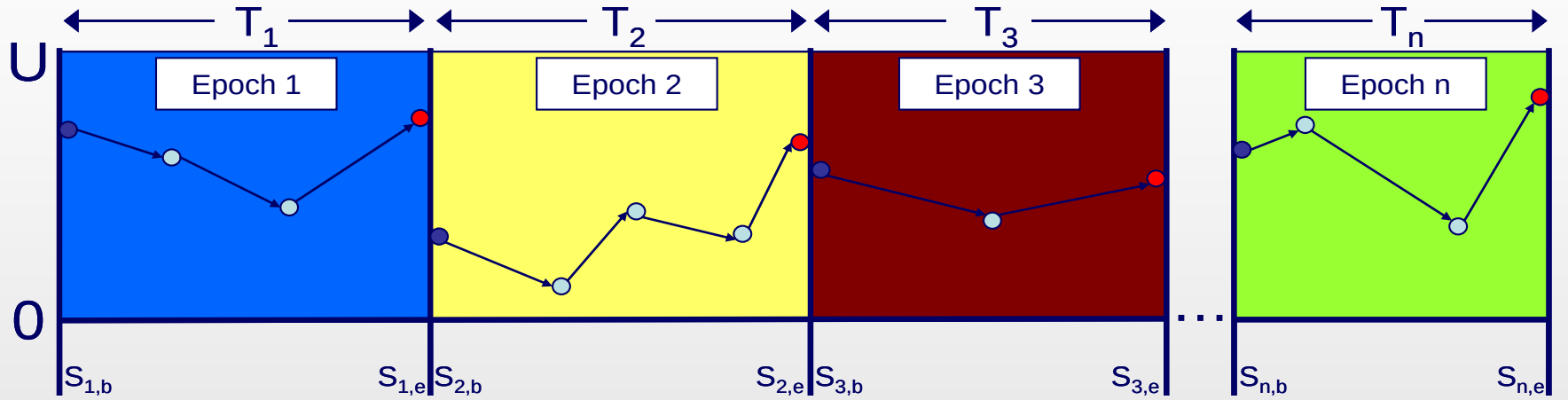


Example triggers for epoch shift impacting enterprise

- Change in political environment
- Entrance of new competitor in market
- Emergence of significant new/changed stakeholder need
- Policy mandate impacting product line, services or operations

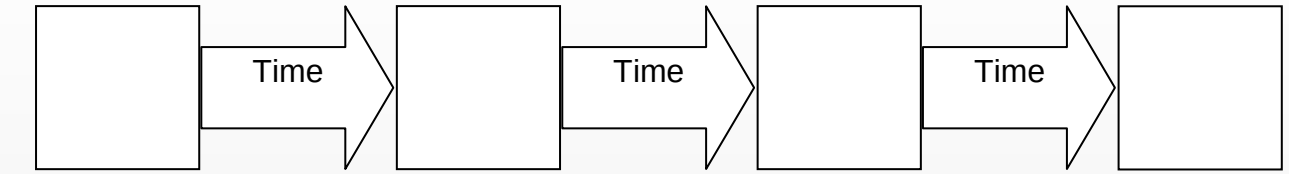
Epoch-based Analysis for "Coffee Enterprise"

classroom illustrative example



Epoch-based Analysis Using 8-View Enterprise Framework

design strategies to address possible futures



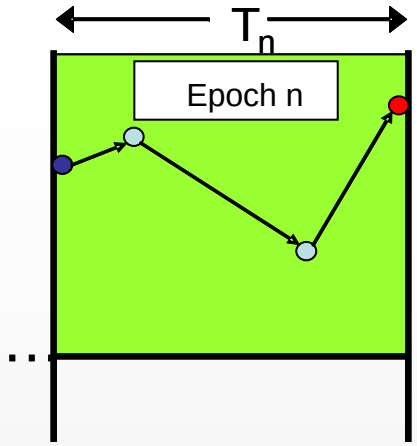
View	Architecture Change Strategies in Response to Epoch Changes
Policy/External	
Strategy	
Process	
Organization	
Knowledge	
Infrastructure	
Products	
Services	

Current approach is to develop strategies for current state to future state enterprise

….epoch-based analysis enriches this by considering strategies across anticipated epochs

Rhodes, D.H., Ross, A.M., and Nightingale, D.J., "Architecting the System of Systems Enterprise: Enabling Constructs and Methods from the Field of Engineering Systems," 3rd Annual IEEE Systems Conference, Vancouver, Canada, March 2009

Epoch-based Analysis "Coffee Enterprise"



The Epoch Vector is composed of the selected epoch variables, which describe the full range of context uncertainties under which enterprise performance will be analyzed.

Variable Types	Epoch Variable	Examples
Strategic Factors	**Brand Coherence**	**Pricing flexibility, standard signage in stores, standard brochures**
Market Factors	**Competitor Profile**	**Competitor enters coffee market**
Policy Changes	**Product/Service Restrictions**	**Food restrictions by FDA, new labor policies limit work hours**
	Allowable Market	**Prohibited market opens**
Economic Factors	**Health of Economy**	**Downturn leading to market size change or product preference change**
Resource Change	**Investment Level**	**Corporate invests heavily in regional growth of new stores**
	Investment Profile	**Corporate funds available for store expansion, test marketing, or IT**
Infrastructure	**Standardization**	**Freedom to choose local supplies, use local accounting auditors, etc.**

Coffee Enterprise Example

View	Architecture Change Strategies in Response to Epoch Changes Healthy --- Downturn --- Prohibition --- Competitor
Policy/External	*Invest in building regional image to strengthen brand.*
Strategy	***1. Expand licensing to areas where economic downturn has less impact (e.g., hospitals, libraries)*** ***2. Partner with companies that offer alternative products with better range of pricing and market*** ***3. Close stores in Epoch 2 where ability to compete in Epoch 4 will be most difficult***
Process	*Incorporate additional criteria into store location evaluation process…*
Organization	*Strengthen capacity to move workforce across stores in hub.*
Knowledge	*Revisit core values to see these withstand the epochs…*
Information	*Centralize IT to save costs, regional adjustments to products and pricing.*
Products	*Introduce alternative products/services for lower cost.*
Services	*Allocate foundation projects at regional level to downturn related causes.*

Examples of Epoch Variables for System of Systems Enterprise

Variable Types	Epoch Variable	Examples of enterprise impacts
Market Factors	***Acquisition Paradigm***	Low incentive for interoperability Interoperability favored in acquisitions Directed SoS acquisition
Policy Factors	***Allowable Constituents***	Limitations to national enterprises Extension to cross-national enterprises
Economic Factors	***Health of Economy***	Healthy economy yields aggressive investment Downturn results in investment cutbacks

Characterization of Views Across SoS Enterprise Epochs (1)

	Epoch 0 Peace-time	**Epoch 1** Net-Centric Technology	**Epoch 2** Conflict Environment
Enterprise Architecture Form	***Collection of Unconnected Systems***	***Collaborative SoS***	***Directed SoS***
Policy/ External Factors	Enterprise motivated to deliver standalone products/services	Net-centric paradigm provides means for collaboration	Threat leads to desire to control by central authority
Strategy	Enterprise delivering single systems	Enterprise collaborates with others for SoS value	Enterprise operates as formal constituent in SoS enterprise
Process	Enterprise-driven with integration to enable business goals	Focus on process interfaces and alignment	Integration of key processes across constituents
Organization	Structured to achieve local goals of enterprise	Federation model to serve both local and global goals	Integrated enterprise favoring global goals as primary

Characterization of Views Across SoS Enterprise Epochs (2)

	Epoch 0 Peace-time	**Epoch 1** Net-Centric Technology	**Epoch 2** Conflict Environment
Enterprise Architecture Form	***Collection of Unconnected Systems***	***Collaborative SoS***	***Directed SoS***
Knowledge	Knowledge sharing within the enterprise	Open sharing or per agreement between constituent enterprises	Control of knowledge at SoS enterprise level
Infrastructure	Local infrastructure	Local infrastructures with loose coupling between enterprises	Commonality across infrastructure with tight coupling
Products/ Services	Responsive to market forces and/or procurer requests	Responsive to pull from stakeholders and push from constituents	Responsive to direction from central authority

Architect's challenge is to look for architectural strategies to address the anticipated epochs across enterprise lifespan

Epoch-Based Approach to Designing Enterprise Transformation

- Enhanced structure provided by rigorous qualitative epoch models enriches classical strategic planning approaches
- Anticipating possible future epochs on continuous basis enables more resilient enterprise
- In future, new modeling approaches will enable deeper analysis to improve enterprise decision making

Case Example: Applying Epoch-Based Thinking to Designing a US Coast Guard Cutter

Epoch-Based Thinking to Enhance US Coast Guard Operational Requirements Development

Recent research incorporated epoch-based thinking into a Five Step US Coast Guard Operational Requirements Development Process, as an implementation of MIT's Responsive Systems Comparison Method:

1. Value-Driving Context Definition
2. Value-Driven Design Formulation
3. **Epoch Characterization**
4. Era Analysis
5. Review

Schofield, D., A Framework and Methodology for Enhancing Operational Requirements Development: United States Coast Guard Cutter Project Case Study, MTI Masters Thesis, May 2009

Epoch Characterization
US Coast Guard Example

Epoch Characterization:

- Start of assessing future uncertainties, how these uncertainties can impact the design, and how project might mitigate these uncertainties
- Each snapshot for specific time period (epoch) can experience dynamic changes significantly impacting design variable choices or value to stakeholders
- Understanding these relationships early with a project can provide an understanding of how to better reduce these dynamic effects

Types of Uncertainties

Technology

Policy

Budget

System of Systems

Missions

From: Schofield 2010

Epoch Characterization Process

Inputs:

- 3.I.1 Project time constraints
- 3.I.2 List of external uncertainties affecting key stakeholder value
- 3.I.3 Key internal stakeholder attributes
- 3.I.4 Design drivers

Activities:

- 3.A.1 Develop external changes
- 3.A.2 Develop changes in attribute levels and new attributes
- 3.A.3 Develop epoch descriptor definitions
- 3.A.4 Assess epoch descriptor to design variable and attribute impact

Outputs:

- 3.O.1 Epoch descriptions
- 3.O.2 Epoch descriptor impact matrix
- 3.O.3 New design variables and attributes

Uncertainties
Coast Guard Cutter Project

- **Technology:** VUAV integration; major C4ISR system upgrade; and new and more capable (size, range, personnel carried) small boats.
- **Policy:** Marine engine emission reductions; reduced copper content from shipboard systems (sea water systems); increased intelligence gathering into government-wide system.
- **Budget:** Loss of acquisition budget prior to IOC; increase in operational funding for increased usage.
- **Systems of Systems:** Deploying with National Security Cutters; new cutter-deployed helicopters.
- **Missions:** Support of arctic region for fisheries; adding environmental cleanup response capability; more frequent international presence particularly for peace keeping missions.

(Schofield 2010)

Outputs:

3.O.1 Epoch descriptions

3.O.2 Epoch descriptor impact matrix

3.O.3 New design variables and attributes

Epoch Descriptor Category	Epoch Descriptor	Units	Range	Constraints
Technology	Availability of VUAV Technology	Level	Small-Large	Requires hangar storage
	C4ISR Racks	Level	Small-Large	Original design space, weight, and power
	Small Boat Size	ft	24-35	C4ISR Info to/from cutter remain same
Policy	Engine Emmissions Rating	Tier	2 to 4	Weight
	Discharge Copper Content	Level	Low-Medium-High	Maintain original system service life
	SCIF Size	Level	Low-Medium-High	Location near operational spaces
Budget	Project Baseline	%	-20	
Systems of Systems	Operational Availability	Dimensionless	0.85-0.92	Major equipment remains same
	Range Increase	%	5 to 20	Same operational conditions
	Helicopter Weight Increase	%	5 to 50	Size less than HH-60
Missions	Ice Region Use	Level	Low-Medium-High	Floating ice capability only
	Equipment Storage	ft^3	Small-Large	Storage only
	Water/Food Storage	% Increase	5 to 20	Same operational conditions

(Schofield 2010)

Outputs:

3.O.1 Epoch descriptions

3.O.2 Epoch descriptor impact matrix

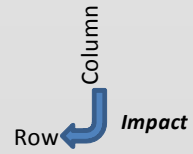
3.O.3 New design variables and attributes

(Schofield 2010)

EPOCH DESCRIPTOR IMPACT MATRIX

Design Variables	Epoch Descriptors	VUAV	C4ISR Racks	Small Boat Size	Engine Emmissions Rating	Discharge Copper Content	SCIF Size	Project Baseline	Operational Availability	Range Increase	Helicopter Weight Increase	Ice Region Use	Equipment Storage	Water/Food Storage	Total Impact
Length		1	0	1	3	0	1	1	0	9	1	3	3	3	**26**
Power		3	0	3	0	1	1	3	3	9	3	9	3	3	**41**
Propulsion Type		1	0	1	9	0	0	9	9	9	3	9	1	3	**54**
Antennae Space		9	9	0	0	0	9	3	3	1	3	1	1	1	**40**
Crew Size		3	3	3	1	1	3	9	9	3	1	1	3	9	**49**
Habitability		1	1	1	3	1	3	3	3	3	1	3	3	9	**35**
Boat Launch System		3	0	9	1	1	0	3	3	3	3	1	1	1	**29**
Hangar Storage Cap		9	0	3	1	0	3	1	1	3	9	1	1	1	**33**
Weight		3	1	9	3	3	3	3	3	9	9	9	9	9	**73**
Material Types		1	0	1	3	9	1	9	3	3	1	1	1	1	**34**
Hull Strength		3	1	3	1	0	1	3	1	9	9	9	3	3	**46**
Total		***37***	***15***	***34***	***25***	***16***	***25***	***47***	***38***	***61***	***43***	***47***	***29***	***43***	
Attributes															
Air Cap		3	3	3	0	0	1	3	3	3	9	3	3	1	**35**
SB Cap		3	1	9	1	1	1	3	3	3	3	3	3	1	**35**
Sensor Cap		9	9	0	1	0	3	3	3	1	3	1	1	1	**35**
Hum Op		3	3	1	3	1	3	1	1	1	1	0	0	0	**18**
Spd to Station		1	1	1	3	1	1	9	3	9	3	3	3	3	**41**
Comms Cap		1	3	0	0	0	1	1	3	1	3	1	1	1	**16**
Range		1	0	1	1	1	3	3	1	9	3	9	9	9	**50**
End		1	0	1	1	1	1	3	3	9	3	3	9	9	**44**
Ice Capability		1	1	1	1	3	1	9	1	9	3	9	3	3	**45**
Environmental Impact		1	0	1	9	9	1	3	3	3	1	3	1	1	**36**
Total		***24***	***21***	***18***	***20***	***17***	***16***	***38***	***24***	***48***	***32***	***35***	***33***	***29***	

Impact Scale: 0-None; 1-Slight; 3-Moderate; 9-High



Revealing New Design Variables and Attributes

Reviewing this impact matrix reveals several key findings

1. Epoch descriptors, project baseline, range increase, and ice region use have the largest impact on both design variable and attributes.
   - This high impact leads to the recommendation that these potential external studies should be well examined before the final requirements or designs are finalized.
2. Propulsion type and weight are design variables most impacted by all epoch descriptors.
   - Leads to importance of ensuring that any design constraints on these two variables are reviewed for potential future uncertainty and review of how changeability could be incorporated into the design.
3. Attributes of range and ice capability were most impacted by epoch descriptors.
   - This means these two potential performance parameters should have significant analysis prior to determining their expected levels of performance.

Era Analysis

Inputs:

- 4.I.1 Project time constraints
- 4.I.2 Epoch descriptions
- 4.I.3 New design variables and attributes

Activities:

- 4.A.1 Develop specific epoch time periods
- 4.A.2 Assign epoch descriptor prioritization by time period
- 4.A.3 Define the system transition rules across epochs
- 4.A.4 Develop era strategies
- 4.A.5 Develop strategy evaluation criteria
- 4.A.6 Evaluate era strategies

Outputs:

- 4.O.1 Era time periods
- 4.O.2 Era descriptions
- 4.O.3 Era rules effects matrix
- 4.O.4 Era strategies
- 4.O.5 Strategy evaluation

(Schofield 2010)

Era Time Periods for Offshore Patrol Cutter (OPC)

- Using project time constraints developed earlier, OPC project can be broken into 4 specific time periods (epochs).
  - These correspond to natural milestones within the programs or changes in how the cutter will be built or used.

Time Periods:

Period 1: Static snapshot - ORD development (present)

Period 2: Present to IOC, approximately 2018

Period 3: IOC until mid-life of cutter, approximately 2033

Period 4: Mid-life to end of service life, approximately 2048

Era Description for Offshore Patrol Cutter (OPC)

- Using epoch descriptions (Process 3) each time period can be characterized by most likely epoch descriptor to occur defining the most likely era to occur (4.A.2).
  - This is determined by experience within past acquisition projects and knowledge of current future systems of systems studies.

ERA DESCRIPTION

Era Name	Time Period	Period Description	Epoch Descriptor	Comments
OPC Most Likely	1	Present	Current State	Snapshot at Present
	2	2010-2018	Ice Region Use	Expand missions into Artic Region
	3	2018-1033	Availability of VUAV Technology	Add mature VUAV capability to cutter
	4	2033-2048	Small Boat Size	Change size of small boat

(Schofield 2010)

Era Rules Effects Matrix for Offshore Patrol Cutter (OPC)

ERA RULES EFFECTS MATRIX
Era Name: OPC Most Likely

Epoch Transition	Rule #	Name	Robustness	Changeability				Parameters Enabling Change	(Schofield 2010) Comments
				Change Agent Type		Change Effect			
			Robust	Flexible	Adaptable	Scalable	Modifiable		
1 to 2	R1	E1-2R1	X					Hull strength increased for ice class designation	Performance and cost likely to be impacted by added weight
1 to 2	R2	E1-2R2		X			X	Original hull design can be built with added hull strength in future without modifying other systems	Weight reserve in original design and understanding performance changes in strengthened cutter
2 to 3	R3	E2-3R1		X			X	VUAV Storage, Antennae Space, C4ISR Space	Space, weight, and power in original design for addition of VUAV
3 to 4	R4	E3-4R1	X					Size of small boat launching systems	Large system capable of varying size boats
3 to 4	R5	E3-4R1		X			X	Size of small boat launch systems	Space/weight/power in original design for upgrade of launch system at future date

Within this most likely OPC era, there are 5 rules that characterize the changeability or design robustness between the four epochs

These rules define the strategies to maintain system utility across epochs

To simplify the analysis, only a maximum of two transitions rules per epoch were reviewed.

Era Strategies for Offshore Patrol Cutter

SYSTEM ERA STRATEGIES

Era Strategy	Rule Sequence	Short Title
A	R1-R3-R4	Strgthned Hull/VUAV Strg/Lg SB Launch
B	R1-R3-R5	Strgthned Hull/VUAV Strg/Mod Launch
C	R2-R3-R4	New Class/VUAV Strg/Lg SB Launch
D	R2-R3-R5	New Class/VUAV Strg/Mod Launch

(Schofield 2010)

Strategy Evaluation for Offshore Patrol Cutter

- Based on system knowledge, four different strategy evaluation criteria emerge: (1) life cycle cost, (2) implementability (cost, effort, and outcome of construction efforts), (3) performance, and (4) designability

STRATEGY EVALUATION
Baseline Strategy: A

		Strategy			
		A	B	C	D
Evaluation Criteria	Life Cycle Cost	N/A	+	+	+
	Implementability	N/A	-	-	-
	Performance	N/A	+	+	+
	Designability	N/A	0	+	+
	Σ +		2	3	3
	Σ –		1	1	1

Legend: + Better; 0 Same; - Worse

(Schofield 2010)

- Equally weighting these criteria is used to evaluate strategies.
- In this first round of evaluation, they are compared to strategy A

Strategy Evaluation for Offshore Patrol Cutter

- Strategies C and D are the most preferred by the criteria and because of the close results, strategy C was chosen to be the baseline in the 2nd round of evaluation

STRATEGY EVALUATION

Baseline Strategy: C

		Strategy			
		A	B	C	D
Evaluation Criteria	Life Cycle Cost	-	-	N/A	+
	Implementability	+	+	N/A	-
	Performance	-	-	N/A	+
	Designability	-	-	N/A	-
	Σ +	1	1		2
	Σ –	3	3		2

Legend: + Better; 0 Same; - Worse

(Schofield 2010)

Based on this strategy selection, the changeability assessment shows that for this era, a flexibly modifiable system is preferred over purely robust systems.

Review (1 of 2)

Based on the analysis during processes 1 through 5, this review serves to summarize the findings.

Inputs:

5.I.1 Process 1-4 outputs

Activities:

5.A.1 Review value proposition and stakeholders

5.A.2 Review attributes and key design variables

5.A.3 Discuss changeability and impact to attributes and design variables

5.A.4 Develop list of important analysis studies

5.A.5 Discuss individual lessons learned

Outputs:

5.O.1 List of present and future important value exchanges

5.O.2 List of important stakeholders in acquisition and operational phases

5.O.3 Attribute and design variable groupings

5.O.4 Changeability impact to project

5.O.5 List of analysis studies

5.O.6 Lessons learned

(Schofield 2010)

Based on the analysis of the OPC project in processes 1 through 4, the following is a summarized list of the outputs (5.O.1 to 5.O.5)

Review (2 of 2)

Design Drivers (Includes Change Related Drivers)

- Length
- Propulsion Type
- Antennae Space
- Crew Size
- Habitability
- Boat Launch System
- Hangar Storage Capacity
- Weight
- Material Types

Attributes (Includes Attributes Related to Change)

- Air Capability
- Small Boat Capability
- Sensor Capability
- Human Operability
- Speed to Station
- Communications Capability
- Range
- Endurance
- Ice Capability
- Environmental Impact

Changeability Impact

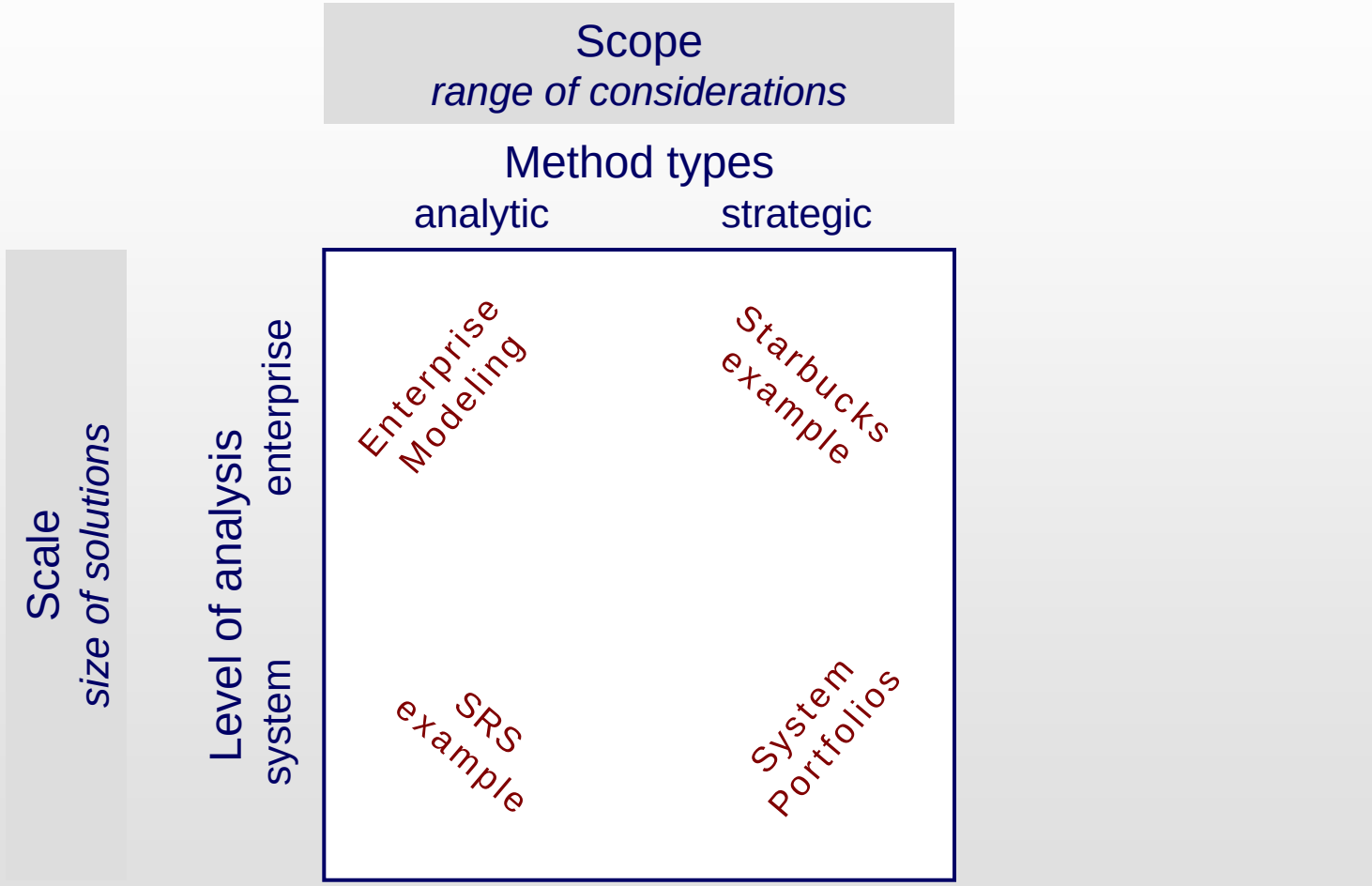
- Small boat launching systems and VUAV modifiability (cost, technology, etc.)
- Hull strength impact to performance attributes (sensitivity analysis)
- Level of ice strengthening necessary for potential ice mission

List of Analysis Studies

- Range effects and sensitivity on design and performance parameters
- Propulsion type effects on design concepts
- Future helicopter deployment study

(Schofield 2010)

Dimensions of Application



Epoch-based thinking can be applied at various levels of analysis and with various supporting methods (both quantitative and qualitative)