Architecting the System of Systems Enterprise: Enabling Constructs and Methods from the Field of Engineering Systems

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Motivation

- Current practice of enterprise architecting insufficient for structural and behavioral complexities inherent in SoS enterprises

- Need for broad holistic approach drawing on systems architecting, and taking into account new paradigms and environmental drivers.

  D.J. Nightingale, D.J., D.H. Rhodes, "Enterprise Systems Architecting: Emerging Art and Science within Engineering Systems," ESD External Symposium 2004, March 2004.

- Architectural decision making typically performed with limited consideration of changing contexts

SoS Enterprise: An enterprise comprised of constituent enterprises managed and operated independently, while simultaneously collaborating to develop, manage and operate an SoS.

Triggering Event
research on enabling constructs and methods

2004 USAF/LAI Workshop on Engineering for Robustness

- One of six recommended research initiatives called for "Considerations for SoS/Enterprise Engineering"

- Experts at workshop agreed *SoS engineering presents new challenges in identifying and achieving convergence in enterprise stakeholder needs, and requires new ways of thinking about and managing such systems.*

D.H. Rhodes, Report on the AF/LAI Workshop on Systems Engineering for Robustness, MIT, July 2004

The field of "Engineering Systems" offers a rich research environment for undertaking this type of research – involving engineering, management, and social sciences

Engineering Systems as Research Landscape

Broad interdisciplinary perspective, embraces technology, policy, management, and social science.

An **intensified incorporation of system properties** (such as sustainability, safety and flexibility)

Enterprise perspective, focusing on interconnectedness of product/system with enterprise

Complex synthesis of stakeholder perspectives, with resolution of conflicting and competing needs

Engineering Systems is an emerging field of scholarship that seeks solutions to complex socio-technical challenges, applying approaches from engineering, social sciences and management.

Ongoing MIT Research

Ultimate goal is a framework for characterizing, designing, and evaluating SoS enterprise architectures throughout the system lifespan as various forces result in entering/exiting of constituent enterprises and systems, changing environment, and shifting enterprise profile

Two elements in emerging framework:

1. **Holistic enterprise architecting framework**
2. **Epoch-based analysis method for identifying architectural strategies by considering possible futures of SoS enterprise**

Hall asserted the need for <u>synthesis of systems methods</u> for "revealing value truths by matching the properties of wanted systems, and their parts, to perform harmoniously with their full environments over their entire lifecycles." A.D. Hall, Metasystems Methodology, Oxford, England: Pergamon Press, 1989
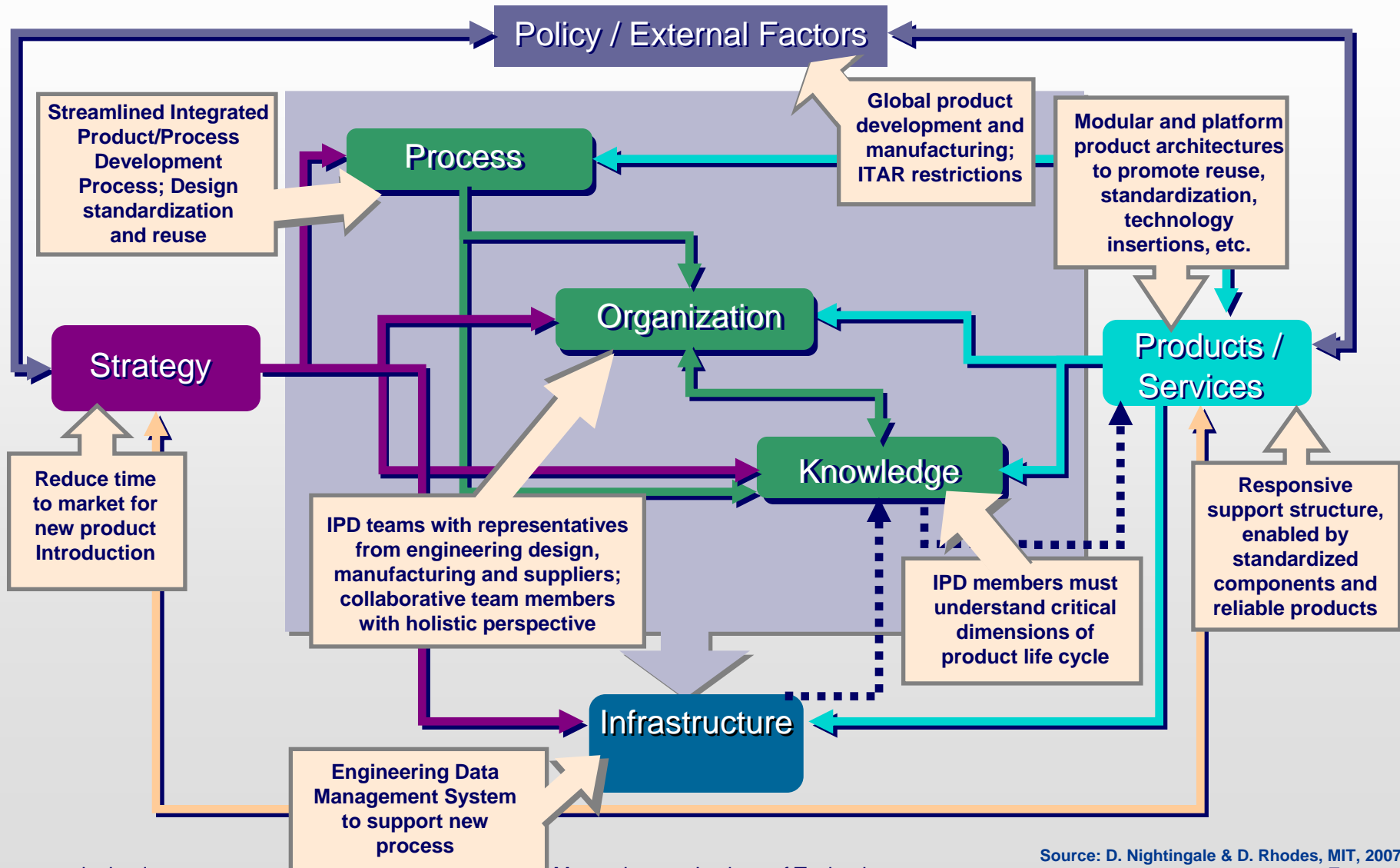
Enterprise Architecting Framework

Nightingale & Rhodes, 2007
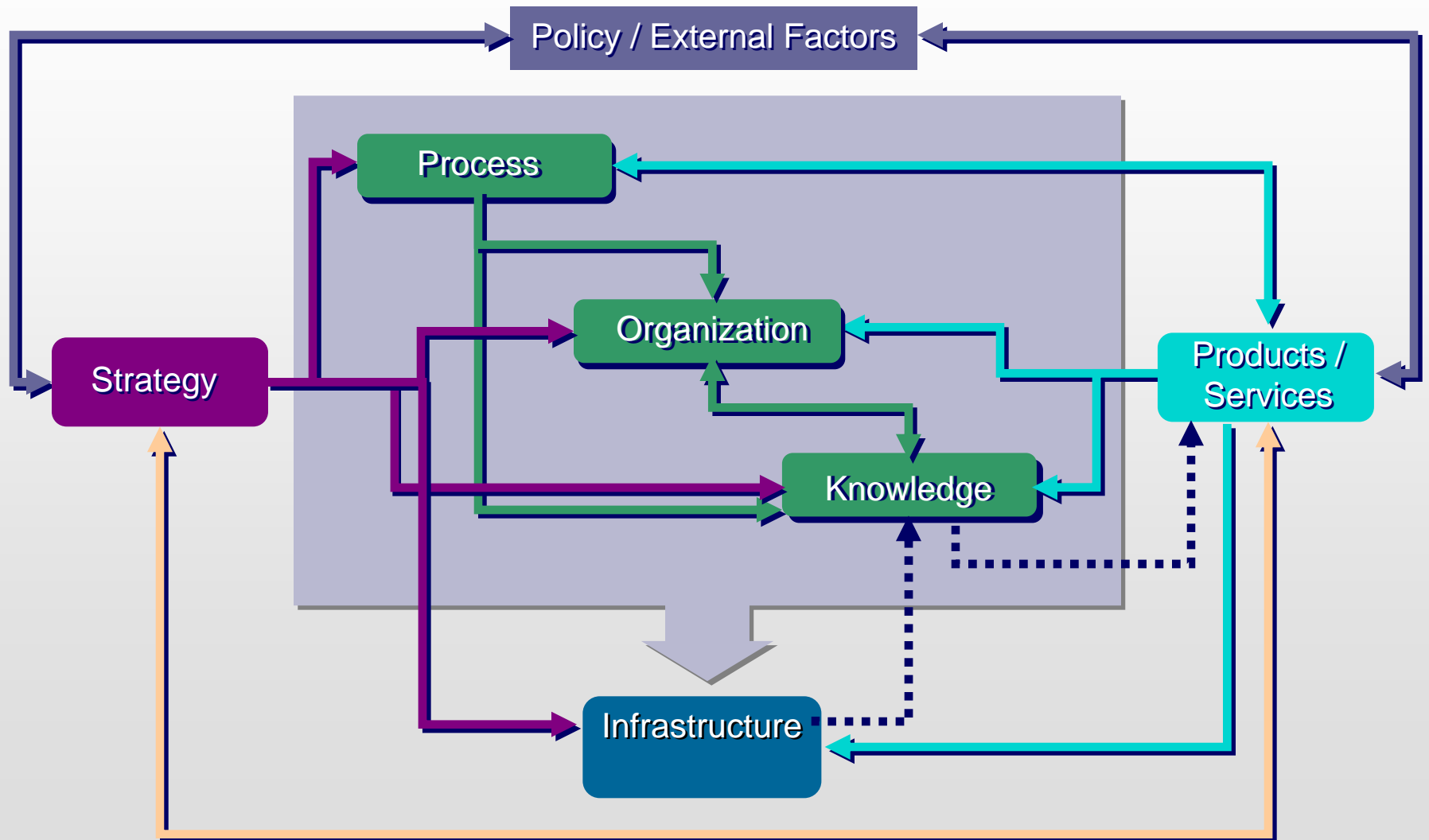
Framework Used to Derive Architectural Strategies

Example: Transform Enterprise to Reduce Time to Market

Policy / External Factors

Streamlined Integrated Product/Process Development Process; Design standardization and reuse

Process

Global product development and manufacturing; ITAR restrictions

Modular and platform product architectures to promote reuse, standardization, technology insertions, etc.

Organization

Strategy

Products / Services

Reduce time to market for new product Introduction

IPD teams with representatives from engineering design, manufacturing and suppliers; collaborative team members with holistic perspective

Knowledge

Responsive support structure, enabled by standardized components and reliable products

IPD members must understand critical dimensions of product life cycle

Infrastructure

Engineering Data Management System to support new process

Understanding Enterprises through Viewpoints

Each view has a structure and a behavior

- For example
  - Organization chart shows a structure


FTSPI Organizational Chart

  - Emergent social networking shows a "behavior"
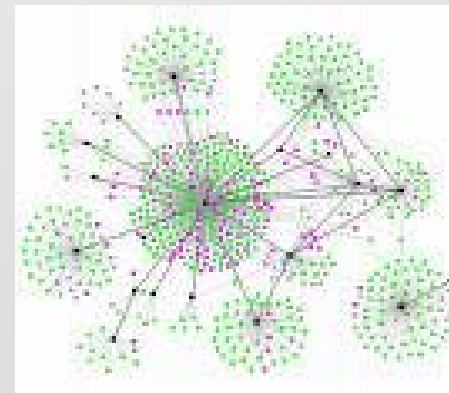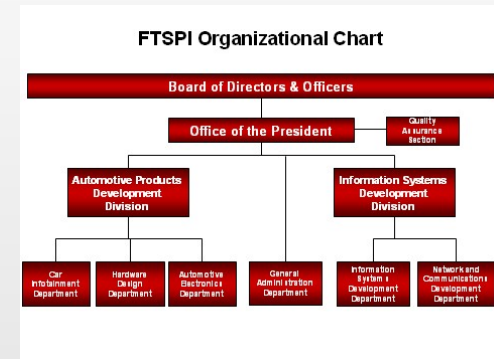
	PROCESS VIEW: The core, enabling, and leadership processes by which the enterprise creates value for its stakeholders.
Structure	▪Integrated versus stovepiped process design ▪Global versus local orientation
Behavior	▪Repeatability of processes ▪Degree of standardization of processes
Artifacts	•Process and value stream maps ▪Process documentation libraries
Measures	▪Productivity and cycle time measures ▪Capability maturity level ▪Process compliance measures
Periodicity	▪Process lifespan ▪Frequency of process audits

Evaluating Enterprise Architectures

Performance Attribute	weight	Sub-Criteria
Efficiency - ability to utilize less resources while improving quality of decisions	50%	How well is knowledge captured and stored within disciplines and projects?
	30%	How well does the architecture increase coordination across products and disciplines?
	20%	How flexible is the process to changing technical decisions or stakeholder needs?
Responsiveness - Ability to directly and rapidly respond to stakeholder needs	50%	Does the architecture deliver the desired stakeholder value?
	50%	Does the architecture include mechanisms for eliciting and responding to changing needs?
Feasibility - ability to implement and sustain enterprise changes	40%	Can the final transformation state be reached in intermediate stable states?
	40%	Is there likely to be sufficient political will to reach the interim and final states?
	20%	Is the scope of the enterprise change achievable within time/ resource constraints?

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During lifespan of the enterprise there are changes in the external context -- some of which we can anticipate – so how can we make decisions now to accommodate future contexts?
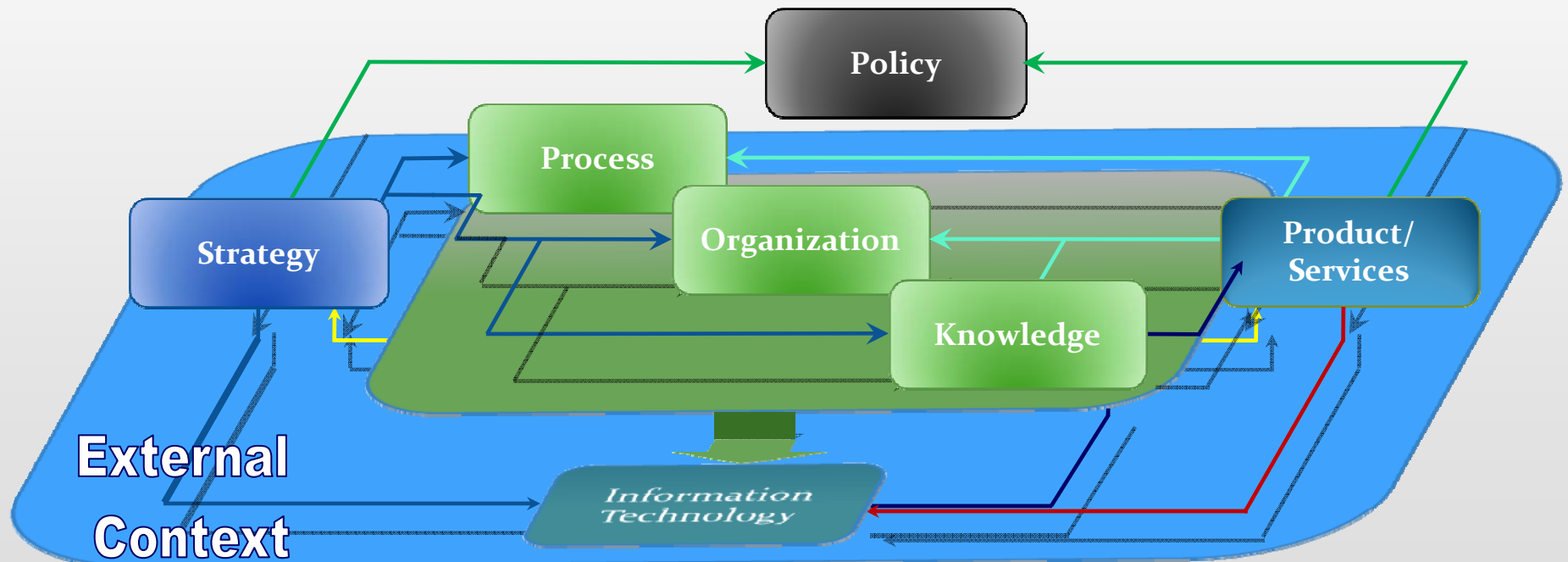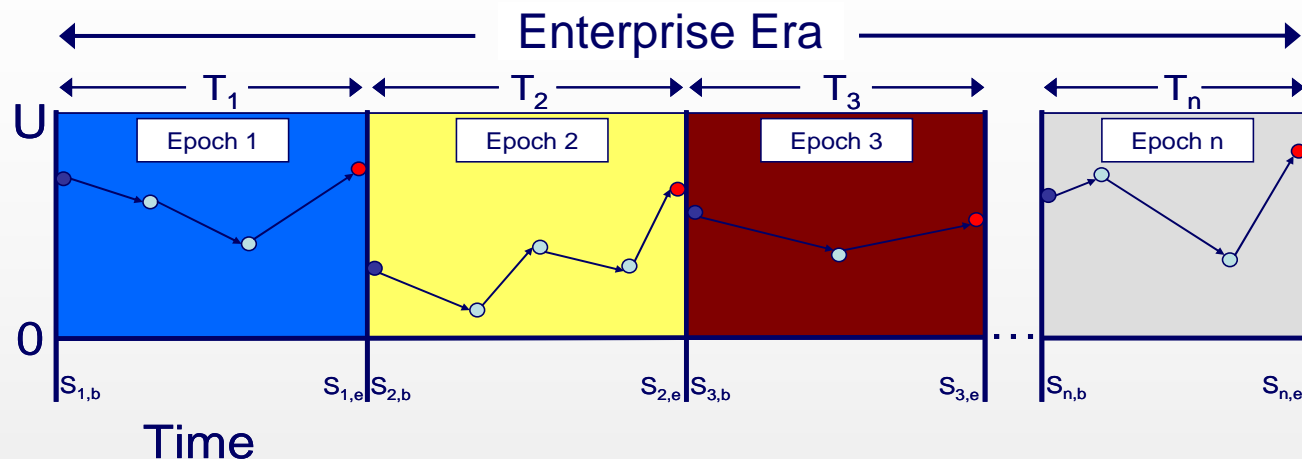
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Epoch-Era Analysis
natural value-centric life cycle

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

Enterprise Era

T_1 — T_2 — T_3 — T_n

U

Epoch 1   Epoch 2   Epoch 3   Epoch n

0

$S_{1,b}$ $S_{1,e}$ $S_{2,b}$ $S_{2,e}$ $S_{3,b}$ $S_{3,e}$ $S_{n,b}$ $S_{n,e}$
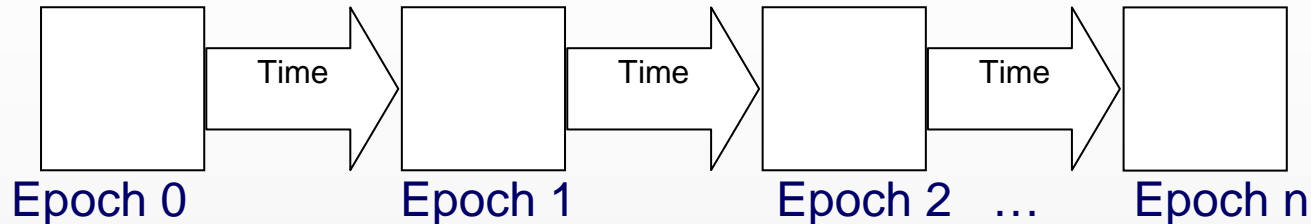
Time

Example triggers for new epoch

- Change in political environment
- Entrance of new competitor in market
- Emergence of significant stakeholder need
- Policy mandate for privatization of enterprise

Epoch-based Analysis
## *design strategies to address possible futures*

| Epoch 0 | →Time→ | Epoch 1 | →Time→ | Epoch 2 … | →Time→ | Epoch n |

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**

Illustration of Constructs
"Classroom" Example

Epoch-based Analysis for "Coffee Enterprise"
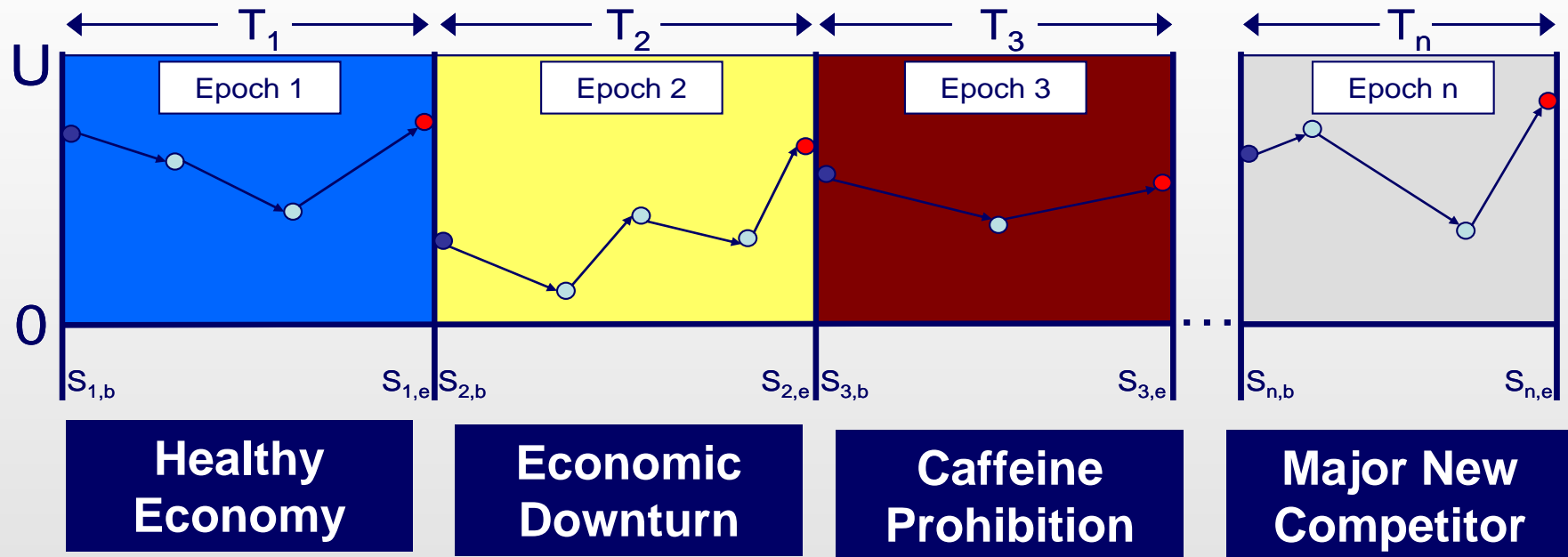
Epoch-based Analysis "Coffee Enterprise"

T_n

Epoch n

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.
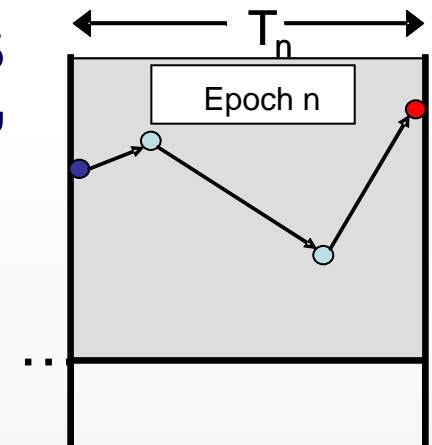
Variable Types	Epoch Variable	Examples
Strategic Factors	**Brand Coherence**	**Pricing flexibility, standard signage in stores, standard brochures**
Market Factors	**Competitor Profile**	**Competitor enters coffee market**
Policy Changes	**Product/Service Restrictions**	**Food restrictions by FDA, new 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 Epoch2 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, egional adjustments to products and pricing.*
Products	*Introduce alternative products/services for lower cost*
Services	*Allocate foundation projects at regional level to downturn related causes'.*

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Applying Constructs
to SoS Enterprise

Examples of Epoch Variables for SoS Enterprise

Variable Types	Epoch Variable	Examples
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 with aggressive investment Downturn with 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

Future Directions

- **Empirical studies of socio-technical contexts of SoS**
  - Better elaboration of epoch variables
  - Identification of effective architectural strategies for value robustness across multiple epochs

- **Enhance methods for identifying architectural strategies across anticipated SoS enterprise contexts**

- **Evolve SoS enterprise architecting framework**
  - Descriptive characterizations of SoS enterprises
  - Evaluation approaches for SoS enterprises
  - Modeling approaches

Resources for Learning More about the Research

Education	Access to Research
Professional and Executive Courses	**websites**

Education — Professional and Executive Courses

Upcoming MIT course…

MIT Short Programs

Architecting the Future Enterprise

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http://web.mit.edu/professional/short-programs/

Access to Research — websites

http://seari.mit.edu

http://lean.mit.edu