System of Systems Research Project Overview

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Agenda

- Introduction
- Research Overview
- SoS Measurement Initiative
- Working Session

Research Overview

- Motivation for Research/Objectives
- Terms of Reference
- Research Conceptual Framework
- Preliminary Research Methodology
- Research Schedule

Workshop Objectives

- Identify measurable concepts and possible measures related to SoS taxonomy
- Map measurable concepts and measures to PSM ICM table
- Review & revise SoS Measurement white paper
- Solicit community insights on research project, methodology, etc.
- Identify potential sources of data, relevant research for incorporation into DAU project

Workshop Deliverables

- Identify measurable concepts related to
  - Elements
  - Interfaces
  - Enterprise Rules
  - Process/Environment
  - Other
- Map SoS measurable concepts to PSM ICM table
- Review/revise white paper
- Identify ideas, issues related to the research methodology or concepts
  - Availability of data
  - Candidate programs
  - Possible confounds & pitfalls

Workshop Timeline

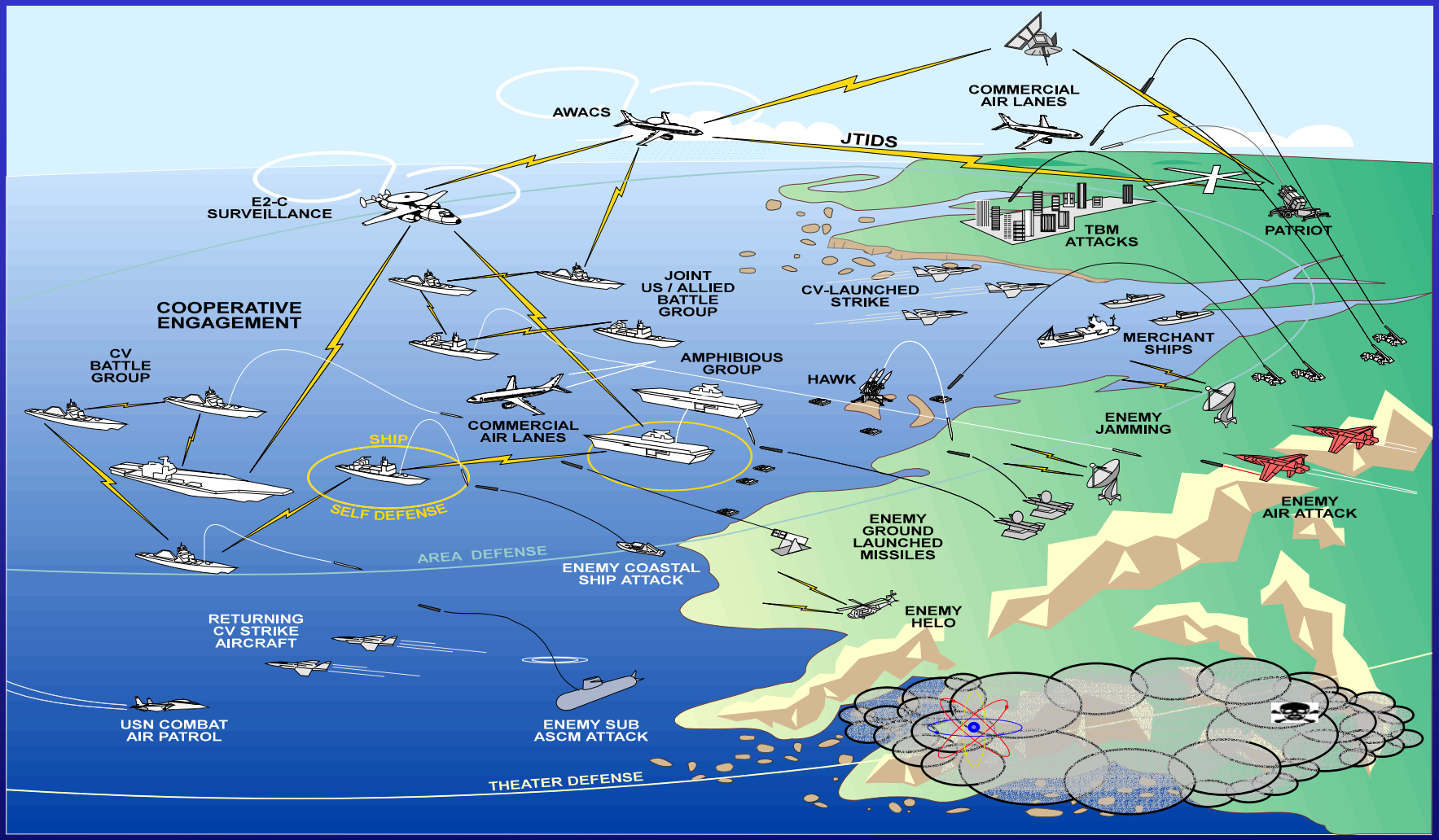
- Morning Session:
  - 0830-0930 Review research
  - 0930-1000 Break
  - 1000-1015 Form into groups
  - 1015-1200 Group discussions, Prepare Presentations
  - 1200-1300 Lunch
- Afternoon Session:
  - 1300-1400 Group Presentations
  - 1400-1430 Break
  - 1430-1600 Review White Paper; Q&A
  - 1600-1700 Wrap-up & Action Items

Research Overview

Motivation for Research

- DoD is doing more integration
  - COTS, NDI focus
  - Forcing “stovepipe” systems to work together
  - Creation of “systems of systems” or SoS
- SoS implementation appears to be problematic
  - Emerging pattern of cost overruns, schedule delays, reduced functionality
  - Planners typically fail to anticipate SoS development and integration challenges
- Overwhelming complexity
- Apparent lack of analytical tools
- Apparent lack of management best practices
- These issues span the DoD and beyond

Motivation for Research



Example: Cooperative Engagement Capability

Observations

- Difficulties in implementing SoS have arisen from 2 major sources
  - Inability to predict the magnitude of the SoS effort
    - Overlook significant drivers of size and complexity
  - Inability to implement SoS efficiently & effectively
    - Lack effective management structures and practices
    - Institutional barriers to efficient implementation
- Resulting outcomes are greater-than-predicted cost and schedule
- Attended by significant “collateral damage”
  - Deferred functionality, budget instability, loss of stakeholder support, etc.

Research Objectives

- Identify significant attributes that impact SoS implementation effort
- Identify management practices that influence SoS implementation outcomes
- Identify and characterize the relationship between observable SoS attributes and lifecycle outcomes (e.g., cost, schedule)
- Stimulate research into the dynamics of SoS
  - Defense Acquisition community
  - Government, Industry, Academia

Terms of Reference: ISO/IEC 15288 System of Interest Structure

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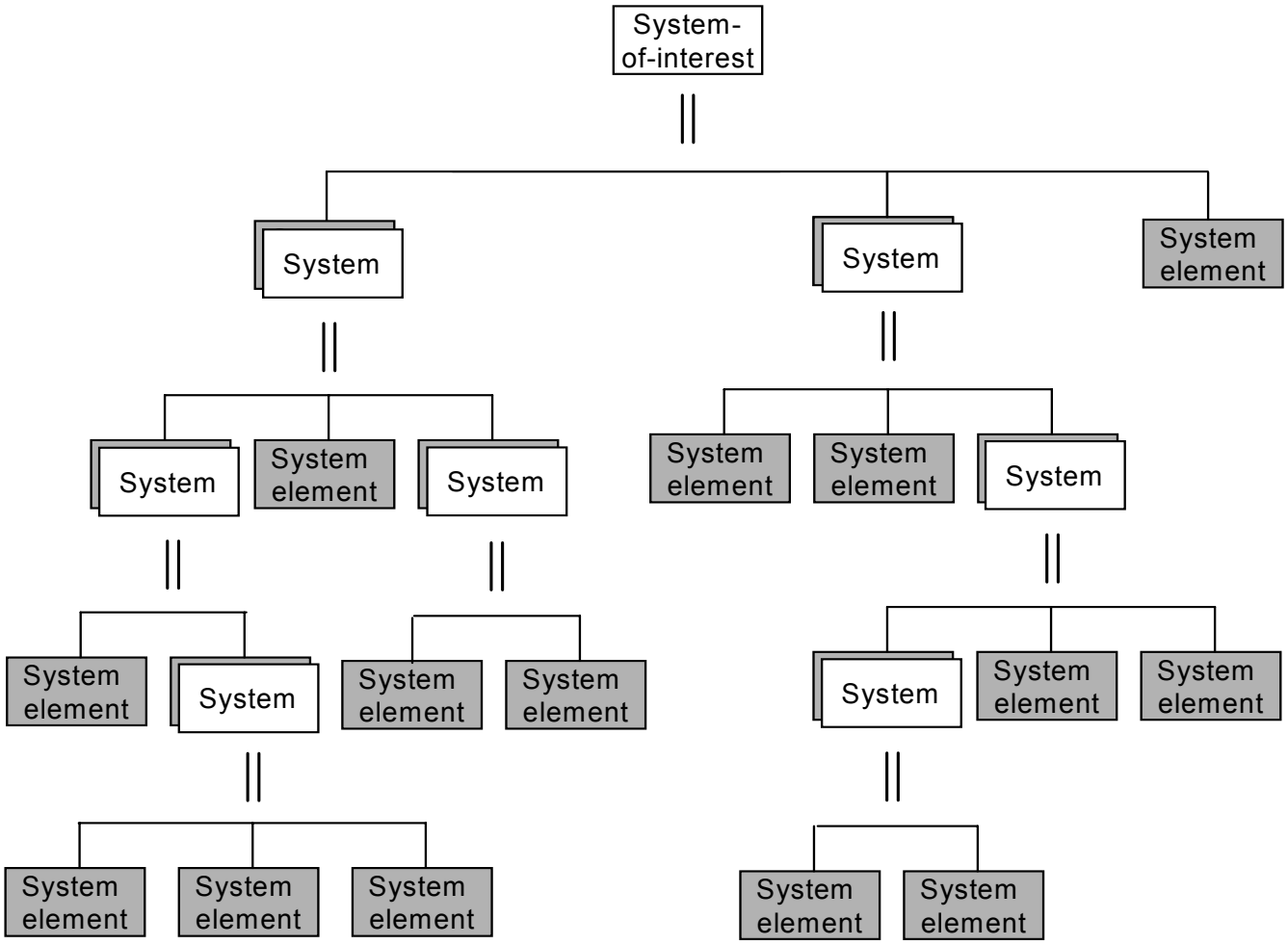


Source: ISO/IEC 15288.

ISO/IEC 15288 Key Terms

- **System**
  - a combination of interacting elements organized to achieve one or more stated purposes
- **System-of-Interest**
  - the system whose life cycle is under consideration in the context of this International Standard
- **System Element**
  - a member of a set of elements that constitutes a system
  - NOTE: A system element is a discrete part of a system that can be implemented to fulfill specified requirements
- **Enabling System**
  - a system that complements a system-of-interest during its life cycle stages but does not necessarily contribute directly to its function during operation
  - NOTE: For example, when a system-of-interest enters the production stage, an enabling production system is required

Source: ISO/IEC 15288, From USC/CSE Presentation to INCOSE IW Workshop by Dr. Barry Boehm & Ricardo Valerdi, Feb 3, 2003.

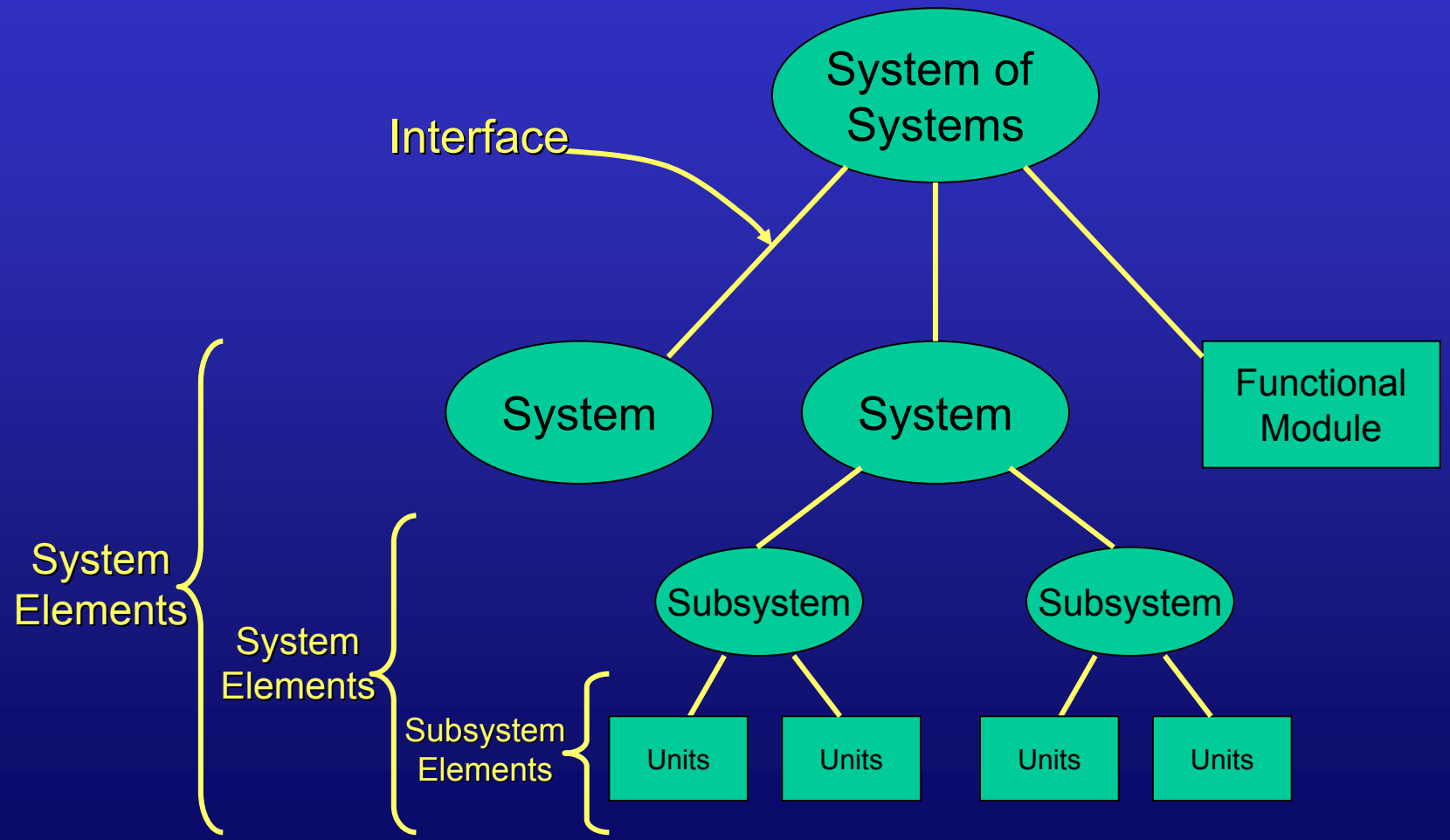
Terms of Reference: System of Systems

- A System-of-Systems (SoS) is a System
  - a combination of interacting elements organized to achieve one or more stated purposes

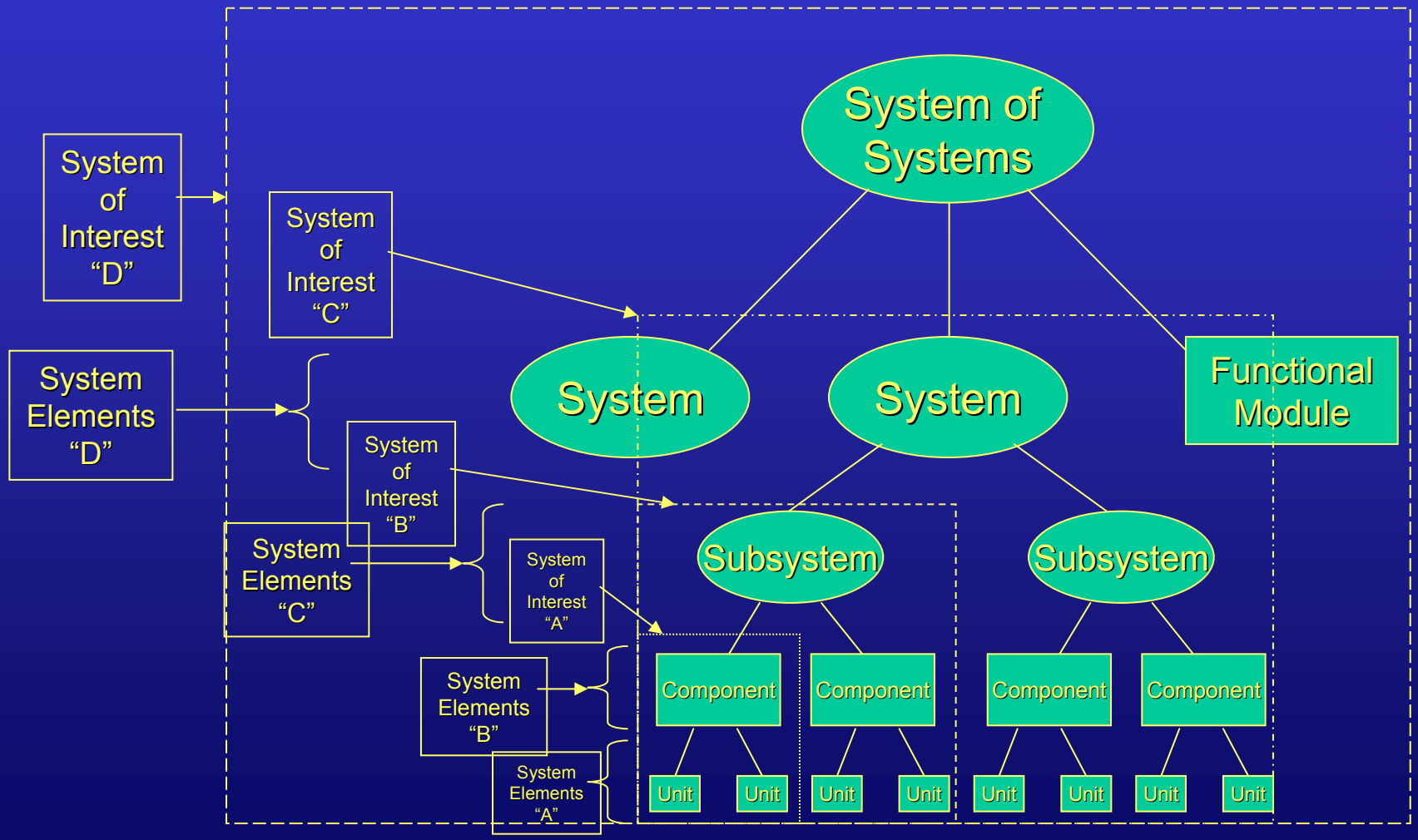
…wherein:

  - System elements are predominantly systems in their own right
  - Important functionality is realized by the functional integration of individual systems elements
    - i.e., individual operational threads pass through multiple system elements

Terms of Reference: System of Systems



System of Interest: Frame of Reference



The Defense Acquisition Management Framework

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- *Process entry at Milestones A, B, or C*
- *Entrance criteria met before entering phase*
- *Evolutionary Acquisition or Single Step to Full Capability*

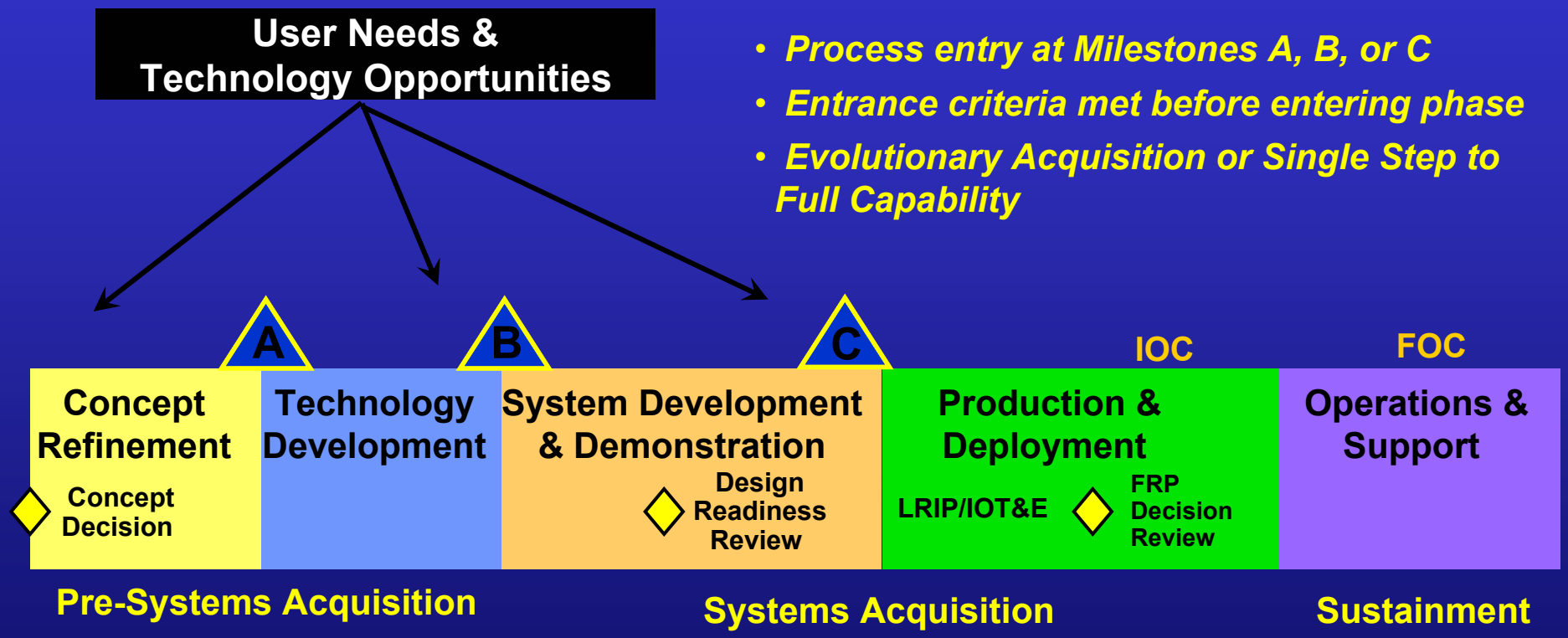
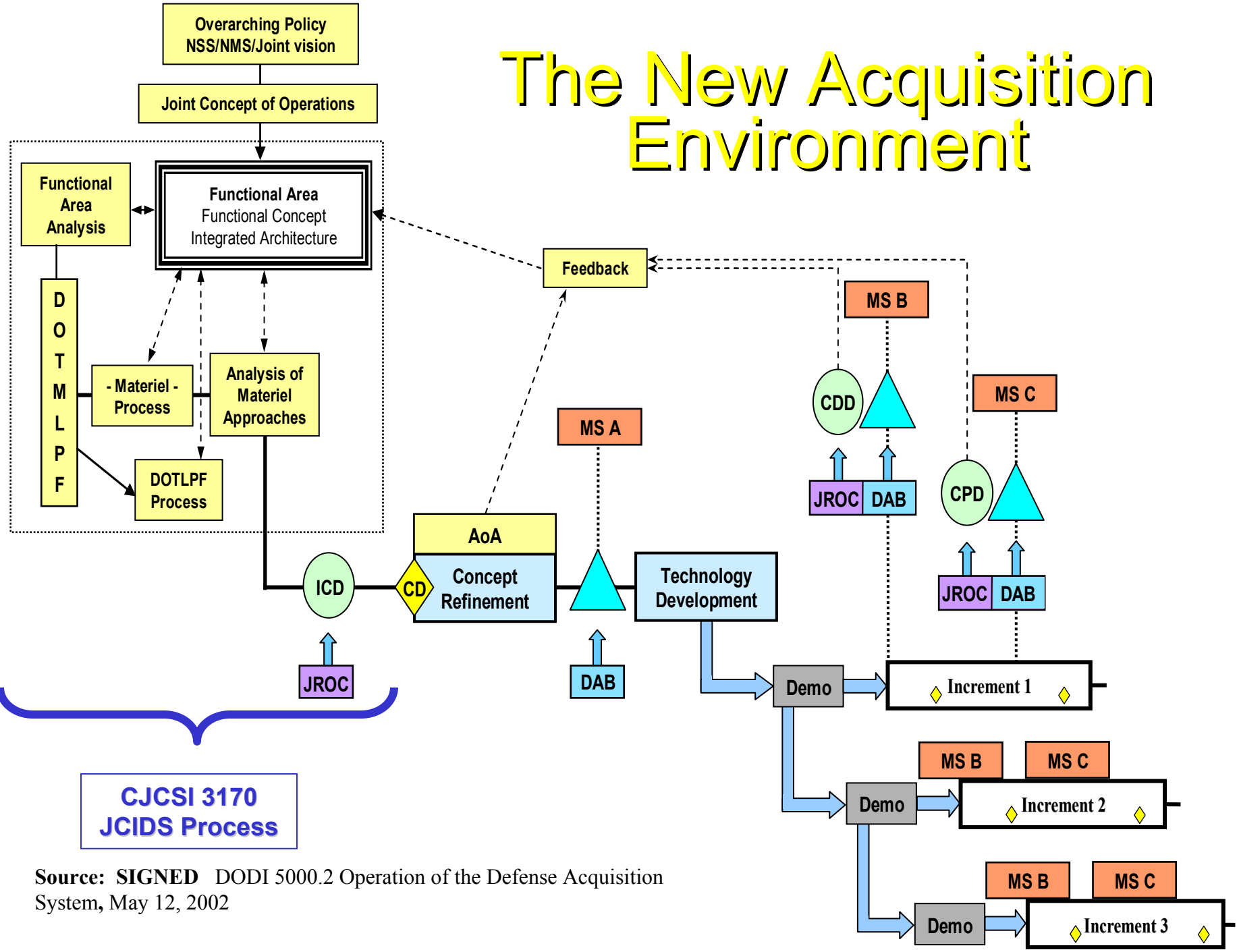


Fig. 1, DoDI 5000.2

The New Acquisition Environment



Source: SIGNED DODI 5000.2 Operation of the Defense Acquisition System, May 12, 2002

Definitions: SoS & FoS

- CJCSI 3170.01C defines S S as follows:
  - SoS: - A set or arra ent systems that are provide a given capabil of the system wi ce or capabi
  - Fo t of independent anged or interconnected in vide different capabilities. The an be tailored to provide desired d epend on the situation

Reconsider?

What's Wrong with 3170 SoS/FoS Definitions?

- No clear distinction between FoS and SoS
  - Both FoS and SoS provide "capability"
  - Distinction between "Interdependent" and "Independent" is difficult to define
  - The notion of "tailoring" a family of systems has no clear meaning—how do you do this?

SoS: - A set or arrangement of interdependent systems that are related or connected to provide a given capability. The loss of any part of the system will degrade the performance or capabilities of the whole

FoS: A set or arrangement of independent systems that can be arranged or interconnected in various ways to provide different capabilities. The mix of systems can be tailored to provide desired capabilities, dependent on the situation

For This Research: Family of Systems Defined

- A Family of Systems (FoS) refers to systems which share certain unifying characteristics
  - Type of functionality provided
  - Mission area supported
  - Common inheritance
- Families are defined
  - To develop functional disciplines
  - To leverage economies of scale
  - To manage investments across domains

Terms of Reference: SoS versus FoS

- A FoS view emphasizes common missions, functions, or inheritance among systems
- A FoS view enables leveraging investments among a portfolio of similar or related systems
  - "Product Line" approach
- A SoS view emphasizes integration of functional elements to achieve a desired operational capability
- A SoS will likely include systems from different families
  - e.g., SoS combining C4I and weapon systems
- SoS and FoS are complementary notions

Terms of Reference: SoS versus FoS

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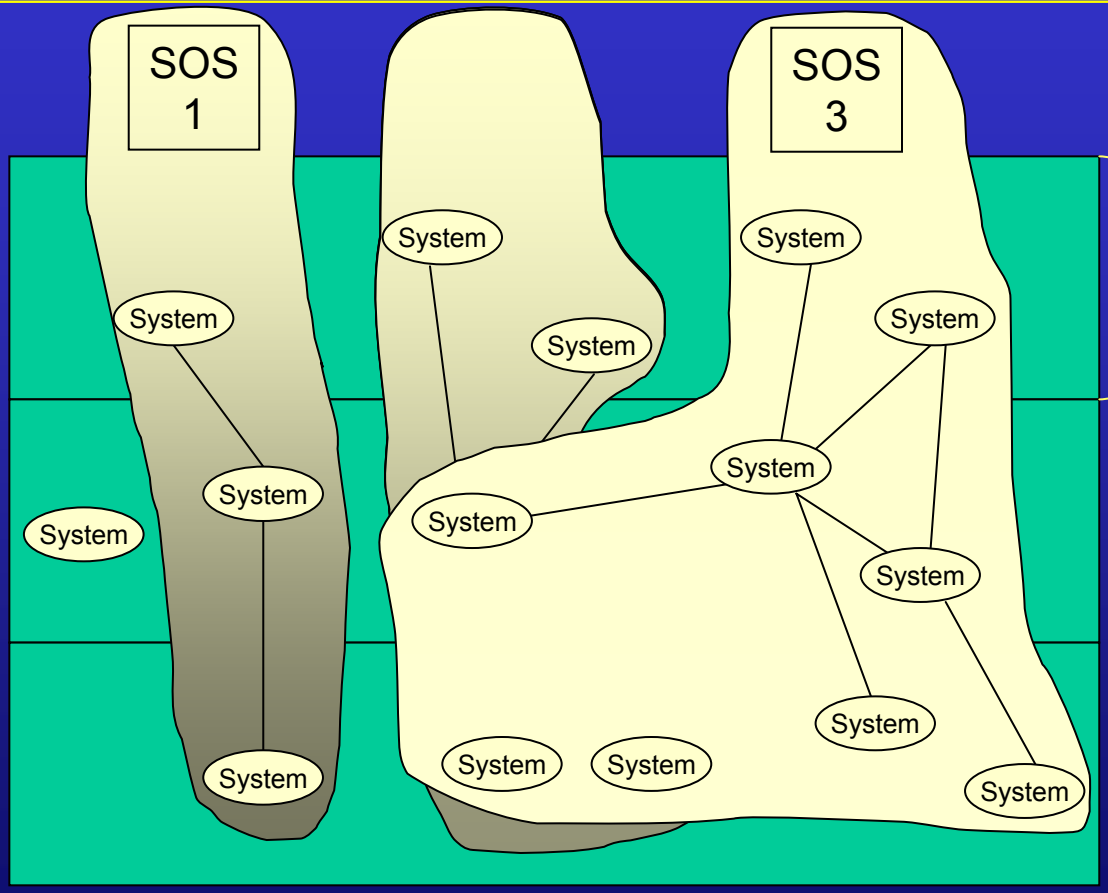
Sensor Family
(e.g. radar, EO, IR)

Platform Family
(e.g. air, ground)

Weapon Family



System "families" share common characteristics, missions, functions, or inheritance.

Individual systems within a Family may be incorporated into one or more SoS, or may not be part of any SoS.

SoS are developed to provide a desired capability by integrating the functionality of individual systems

A Given SoS may incorporate systems from multiple Families

SoS Process Model

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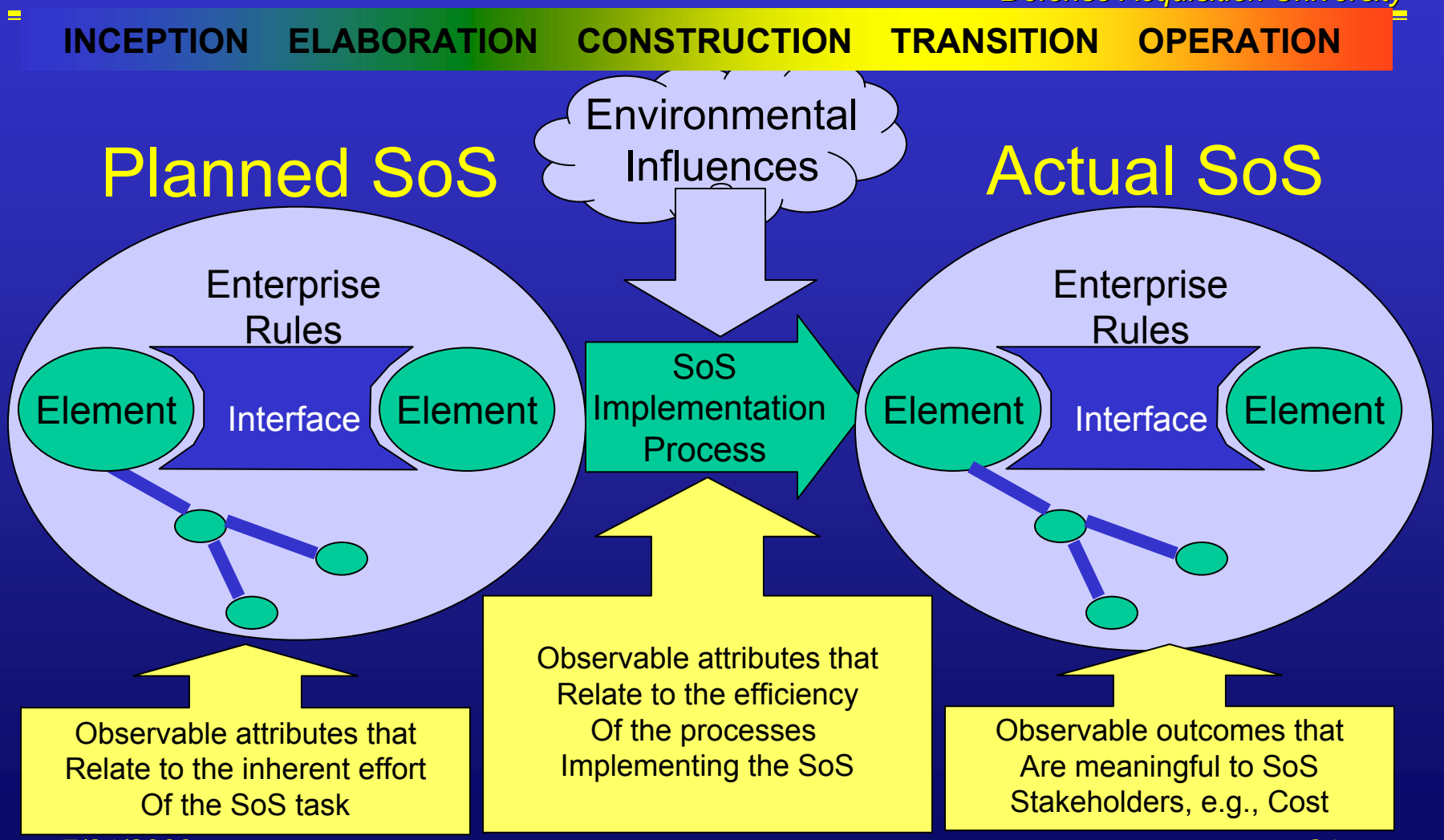
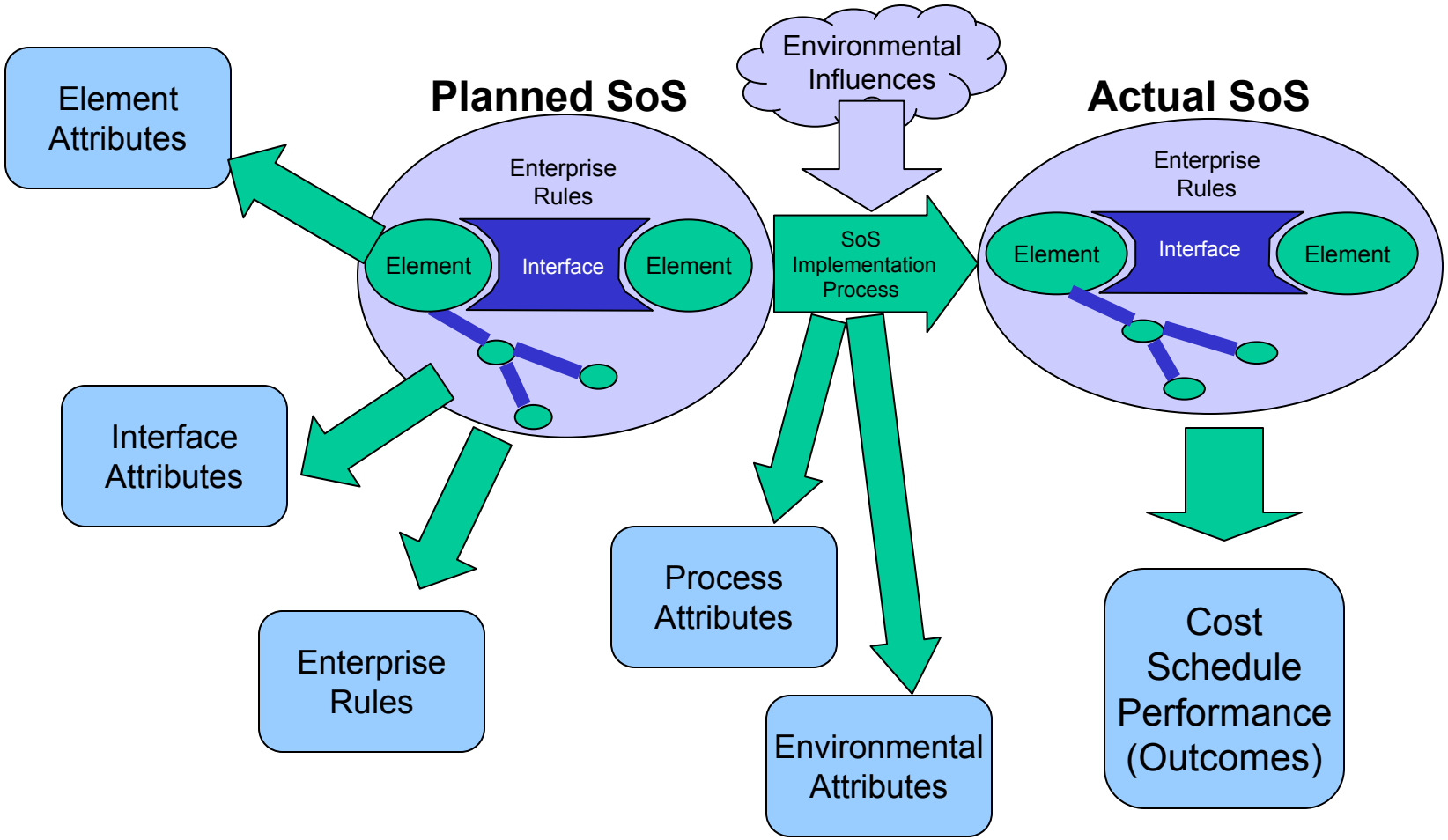
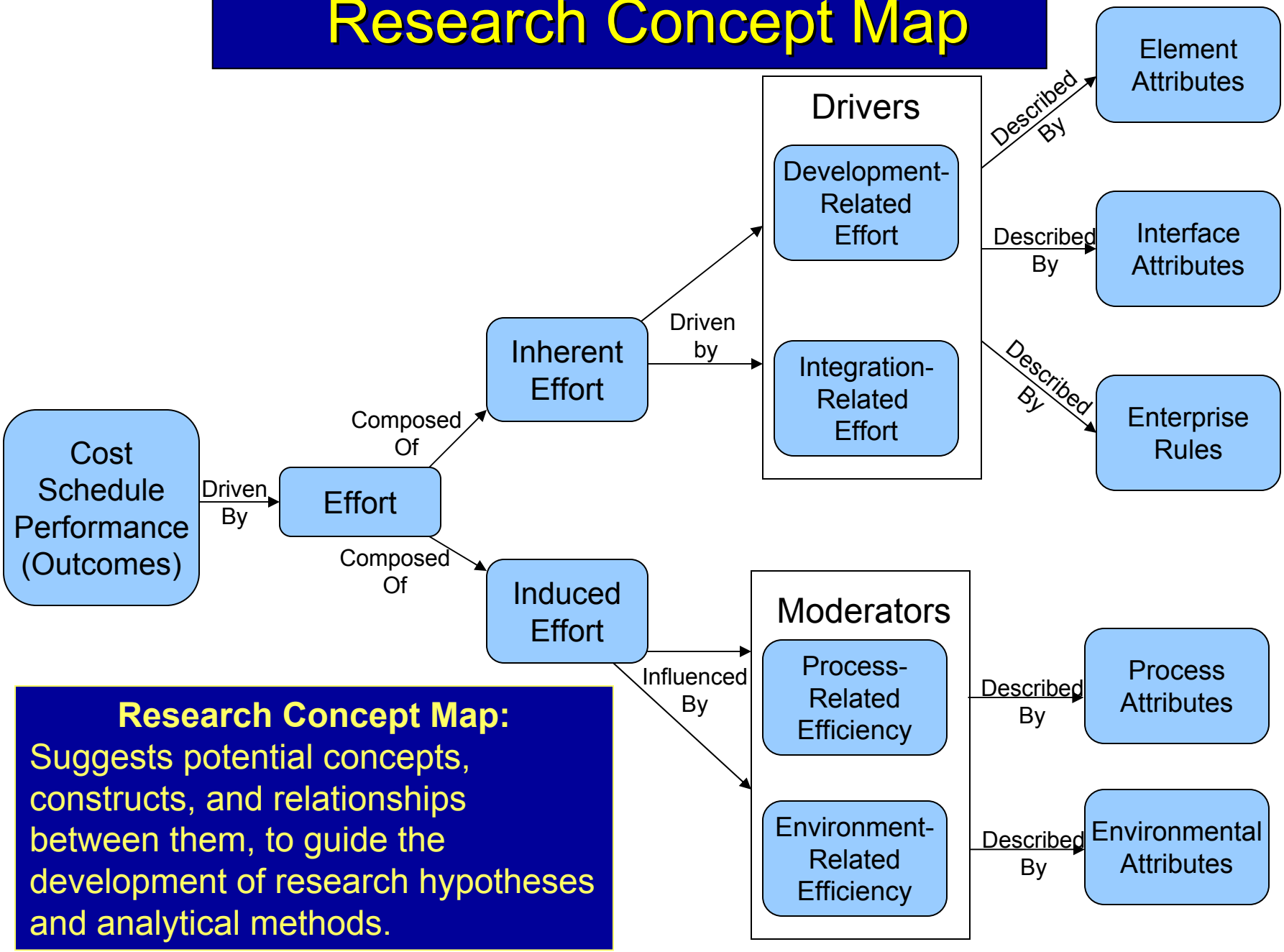


Attributes & Their Sources



"But How Do They Relate to One Another?"

Research Concept Map



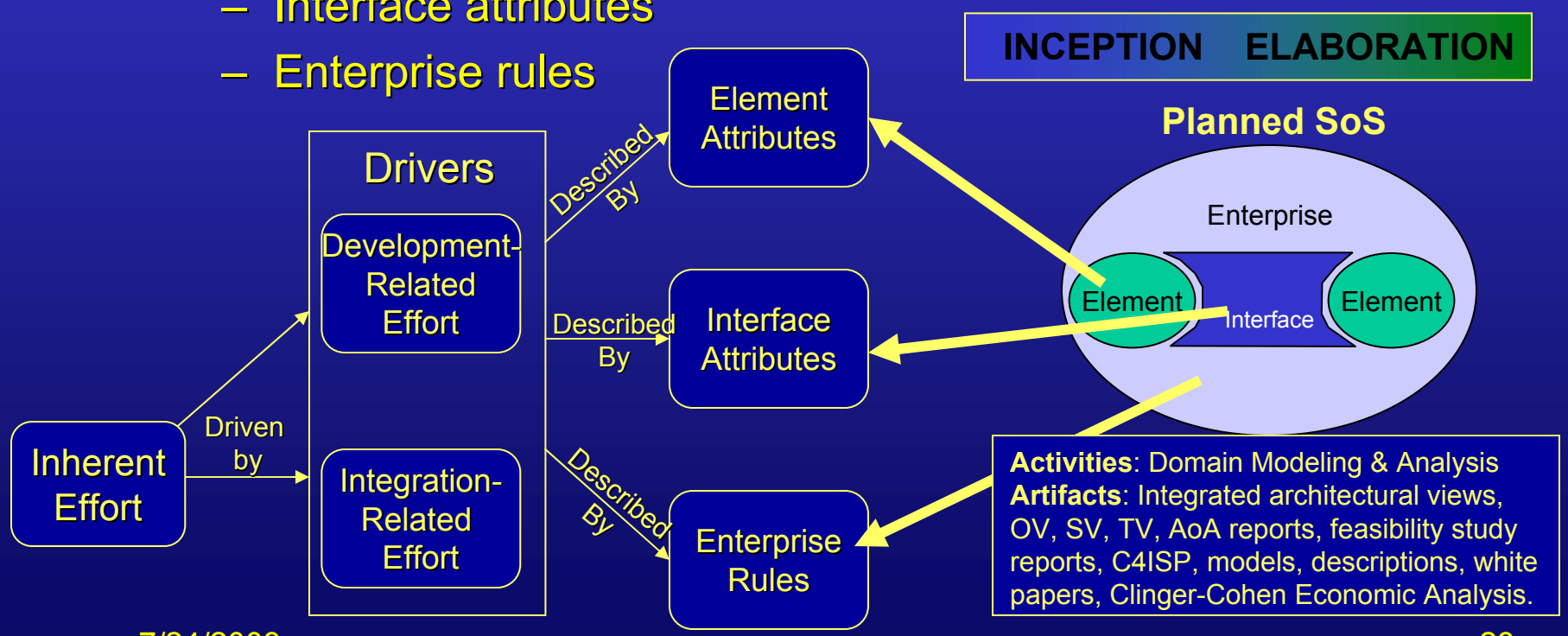
Research Concept Map:
Suggests potential concepts, constructs, and relationships between them, to guide the development of research hypotheses and analytical methods.

Research Framework

- Our research will investigate
  - Drivers of inherent effort
    - Attributes that drive the magnitude and complexity of the project
  - Drivers of induced effort
    - Attributes that influence efficiency of SoS implementation
      - Environmental attributes
      - Process attributes

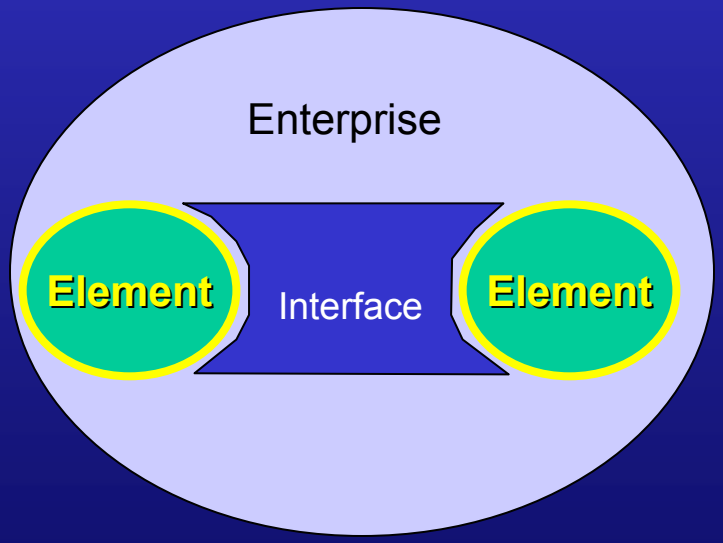
Drivers of Inherent Effort

- Within this model, we assert that the SoS attributes that drive inherent effort fall into three major categories
  - Element attributes
  - Interface attributes
  - Enterprise rules



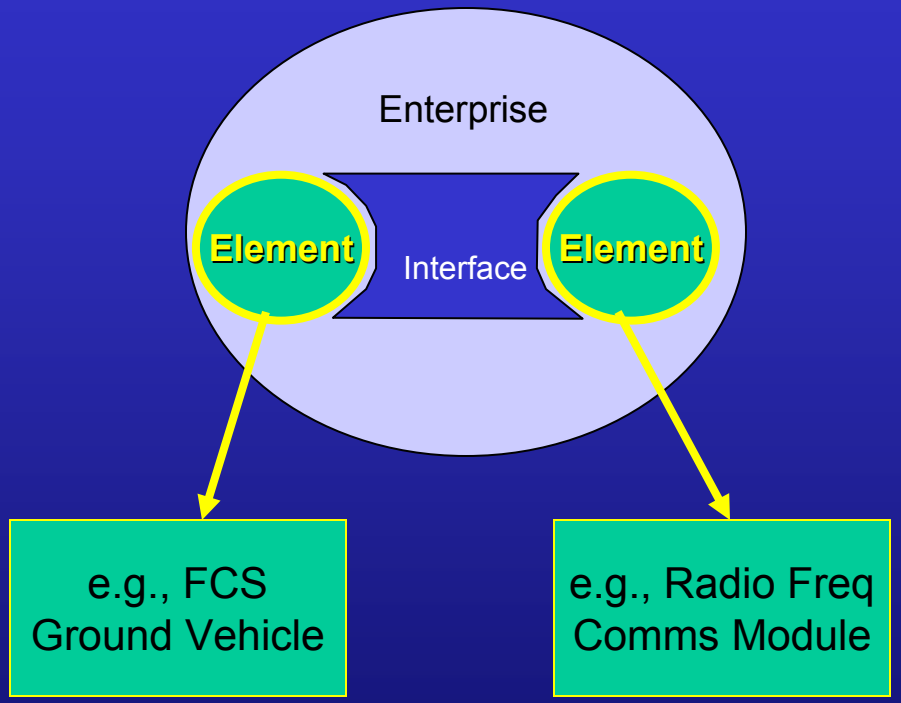
Effort Drivers: Overview

- System Elements
  - System Interfaces
  - Enterprise Rules



System Elements

- System Elements
  - May be functional components
  - May be complex systems in their own right
  - Each may interface with multiple other elements
  - Each must behave according to established enterprise rules



System Element Attributes

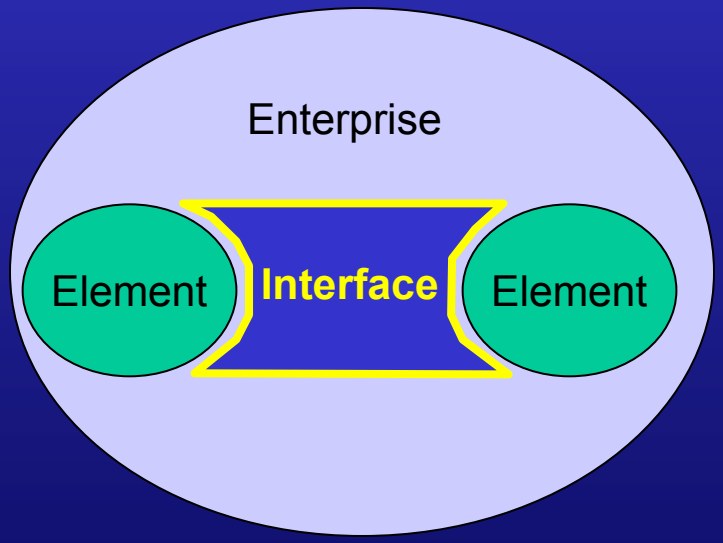
- System-level effort drivers are relatively well-characterized (many cost models exist)
  - Size (SLOC, FP, cards, modules, etc)
  - Complexity (algorithmic, manufacturing, etc)
- There may be additional system element attributes that come into play at the SoS level

System Element Attributes Relevant to SoS

- Number and Size of System Elements
- System Element Design/Complexity
- Homogeneity of System Element design
  - Procedures
  - Architectures
  - Infrastructure
  - Data
- Percentage of elements to be integrated versus built
  - Degree of reuse
  - How many are COTS or NDI?
- Number/complexity of Algorithms
- Others

Effort Drivers: Overview

- System Elements
- **System Interfaces**
- Enterprise Rules



System Interfaces

- Creation of SoS requires <u>integration</u> of system elements
- Integration deals with establishing interfaces between/among components to achieve SoS functionality
- Interfaces must be developed and maintained over the lifecycle of the SoS
  - Requires expenditure of effort over lifecycle
- Attributes of system interfaces may be significant drivers of system element integration effort

Integration & System Interfaces

- Integration is the establishment and maintenance of a functional interface between any two system elements/components
- Interface is a generic term that covers all interactions at all levels of abstraction
  - Application Layer
  - Presentation Layer
  - Session Layer
  - Transport Layer
  - Network Layer
  - Data Link Layer
  - Physical Layer

Example:
Open System Interconnection (OSI) Reference Model

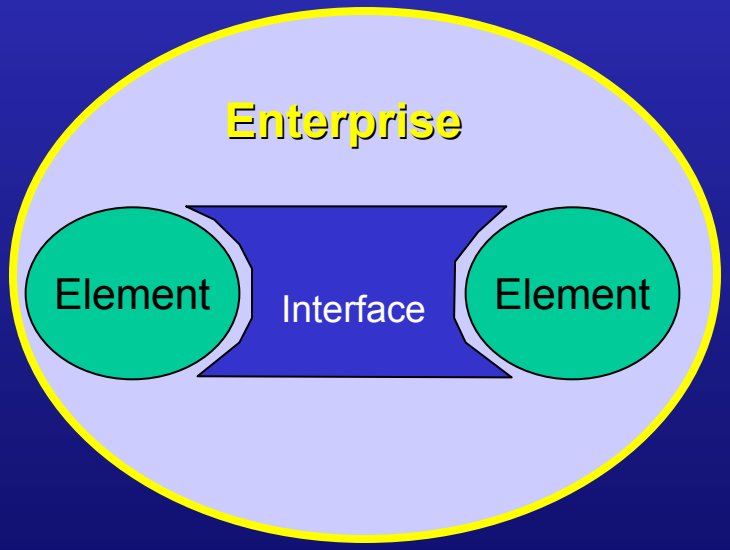
Potential Effort Drivers: System Interfaces

- Number of Interfaces
  - Internal
  - External
- Nature of Interfaces
  - Complexity
  - Volatility
  - Diversity
  - Criticality
  - Security
- Others

Effort Drivers: Overview

- System Elements
- System Interfaces

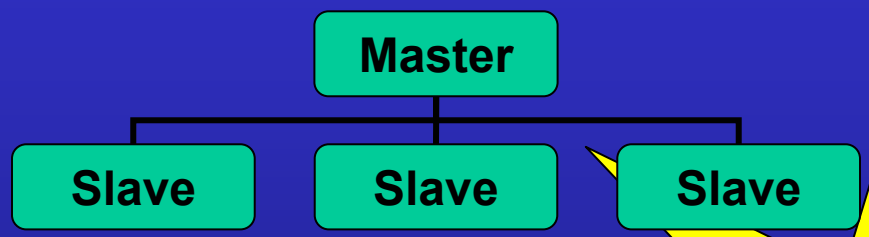
- Enterprise Rules

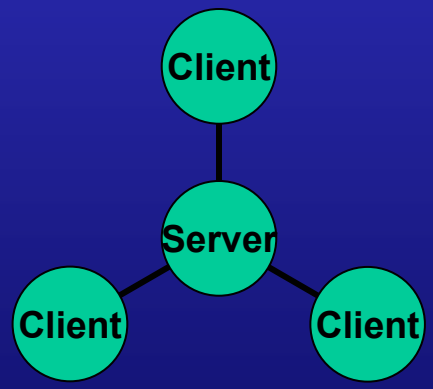


Enterprise Rules

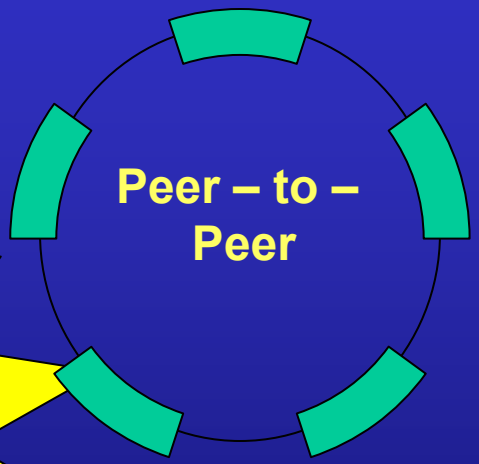
- Creation of SoS requires the establishment of enterprise rules that govern interaction among the elements
- System elements must implement and adhere to enterprise rules
  - System elements must play by the rules to interoperate effectively
- Enterprise rules can drive the effort required to achieve interoperability among the elements

Enterprise Rules Example: SoS Topology





Which form of "government" is the most cost effective?



Each SoS Topology imposes specific rules and requirements upon the constituent system elements. The degree to which the elements can accommodate these requirements will determine the effort required to integrate & maintain the SoS

Examples of Enterprise Rules Attributes

- Synchronous vs Asynchronous
  - Timing constraints for near-real-time SoS
  - Example: sensor-to-shooter applications
- Deterministic vs Stochastic
  - Criticality of event timing/sequencing
    - Particularly important in synchronous applications
- Percent of Total functions that are “global”
  - “thin” versus “fat” clients (distributed components)
- Security, privacy, and safety
- Others

Research Framework

- Our research will investigate
  - Drivers of inherent effort
    - Attributes that drive the magnitude and complexity of the project
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Research Framework

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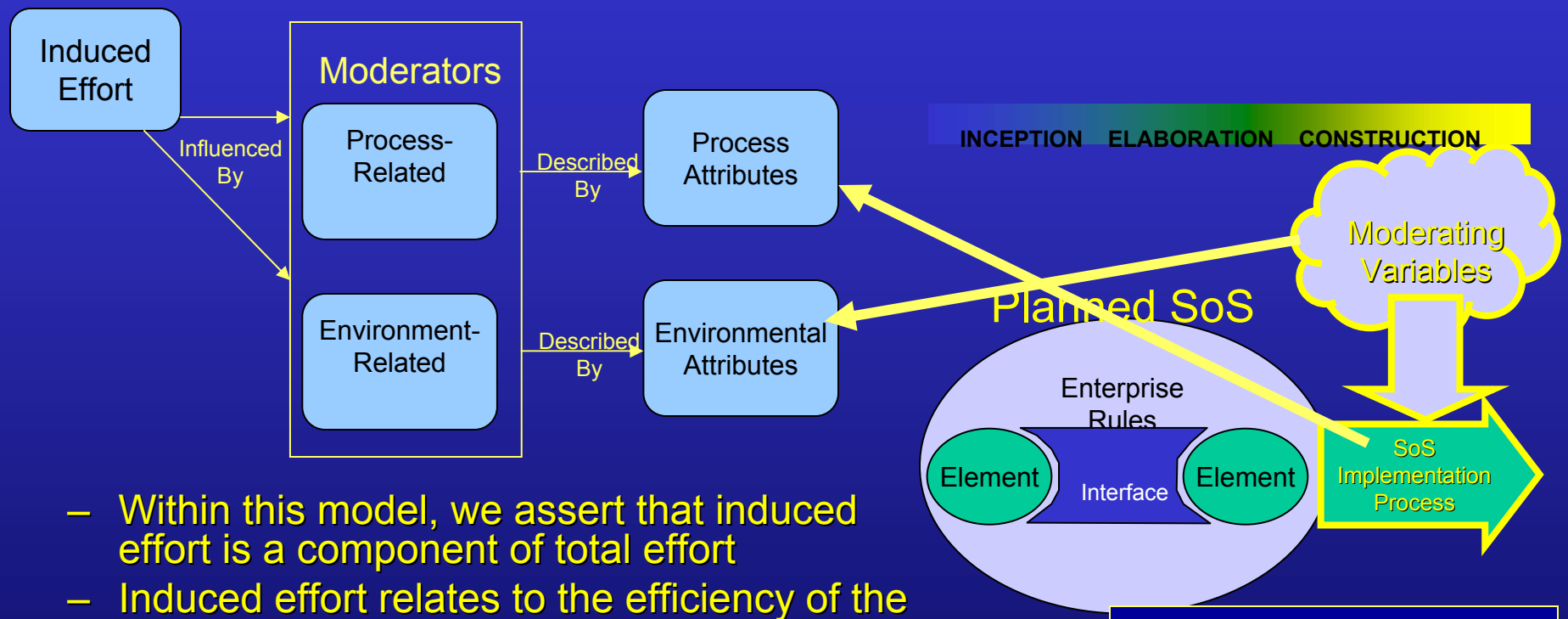


- Within this model, we assert that induced effort is a component of total effort
- Induced effort relates to the efficiency of the SoS implementation process
- Attributes that influence efficiency of SoS implementation
  - Environmental attributes
  - Process attributes

Activities: Implementation strategy planning, PPBS, AoA, IPT meetings, status reporting
Artifacts: Implementation & acquisition strategies, specifications, SOWs, PPBS exhibits, DAES reports, IPT briefings

Moderating Variables

- Moderating variables are attributes of the process and environment which influence the efficiency of SoS implementation process
  - ***Process attributes*** are factors that are typically within the control of the SoS implementer
  - ***Environmental attributes*** are factors that are typically outside the control of the SoS implementer
- Distinctions between "process" and "environment" moderators depend upon the frame of reference & system of interest
  - What may be a "process" attribute at the SoS level may be an "environmental" attribute at lower levels

Process Attributes

- Acquisition Process
  - What strategy is the SoS implementer pursuing?
    - Single-step to full capability
    - Evolutionary
    - Incremental
- Process maturity
  - Are acquisition processes sufficiently mature to implement the SoS?

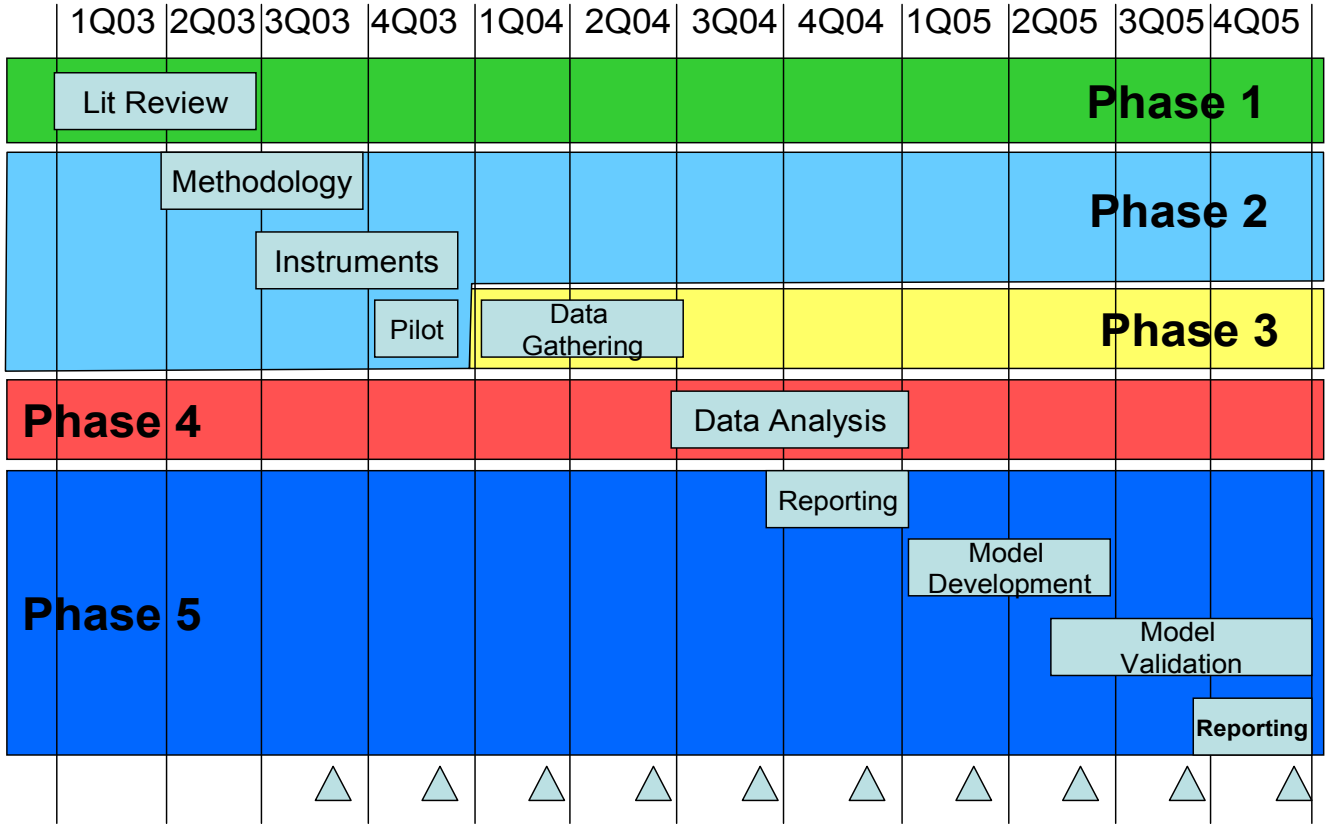
Environment Attributes

- Resource Stability:
  - Are the resources allocated to SoS implementation stable over the implementation period?
  - Does the SoS implementer have the ability to identify and maintain resource requirements over the implementation period?
- Unity of Command:
  - Does the SoS implementer exercise control over the development and evolution of individual system elements/components?
  - Does the SoS implementer have the ability to allocate resources and requirements across the system elements?
  - Can the SoS implementer apply risk management strategies at the SoS level?

Proposed Methodology

- Define relevant attributes
  - System Elements
  - System Interfaces
  - Enterprise Rules
  - Moderating variables (process & environment)
- Conduct retrospective study of SoS
  - Define candidate SoS
  - Gather element/interface/enterprise attribute data
  - Gather moderator/context data
  - Gather results/outcomes from the selected SoS
  - Analyze to determine relationships

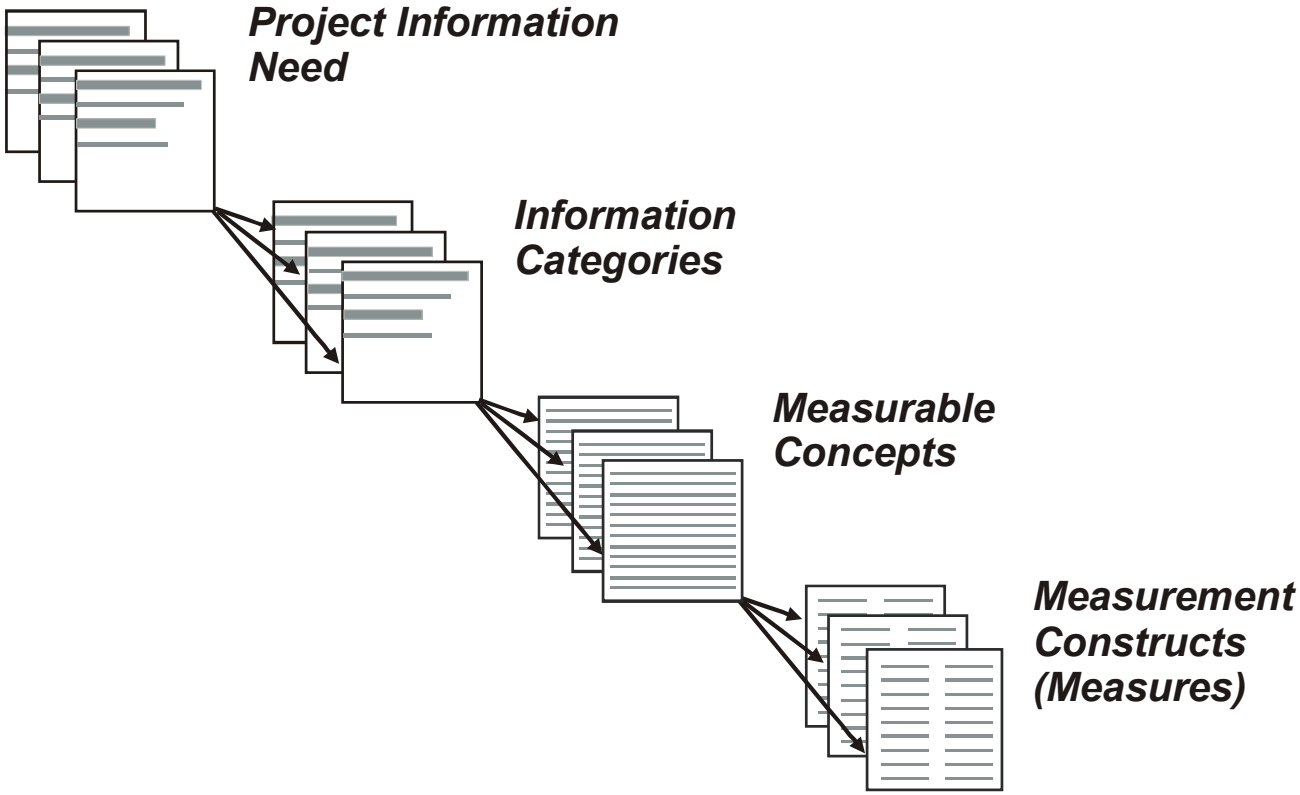
Research Schedule



Summary

- Our goal is to provide useful insights to SoS decision makers
- Identify leading indicators for
  - Drivers of inherent SoS effort
  - Moderators of implementation efficiency
  - Demonstrated “best management practices” and key risk drivers
- These will help decision makers to
  - Establish robust SoS implementation plans
  - Obtain/defend adequate resources for SoS implementation and support
  - Establish realistic expectations for SoS outcomes

PSM Measurement Hierarchy



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Information Categories

- Schedule and Progress
- Resources and Cost
- Product Size and Stability
- Product Quality
- Process Performance
- Technology Effectiveness
- Customer Satisfaction

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PSM Mapping of Information Categories, Concepts, and Measures

Information Category - Measurable Concept - Measure		
Information Categories	**Measurable Concepts**	**Prospective Measures**
Schedule and Progress	Milestone Completion	Milestone Dates
	Critical Path Performance	Slack Time
	Work Unit Progress	Requirements Traced Requirements Tested Problem Reports Opened Problem Reports Closed Reviews Completed Change Requests Opened Change Requests Resolved Units Designed Units Coded Units Integrated Test Cases Attempted Test Cases Passed Action Items Opened Action Items Completed
	Incremental Capability	Components Integrated Functionality Integrated
Resources and Cost	Personnel Effort	Staff Level Development Effort Experience Level Staff Turnover
	Financial Performance	BCWS, BCWP, ACWP Budget Cost
	Environment and Support Resources	Quantity Needed Quantity Available Time Available Time Used
Product Size and Stability	Physical Size and Stability	Database Size Components Interfaces Lines of Code
	Functional Size and Stability	Requirements Functional Changes Function Points

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PSM Mapping of Information Categories, Concepts, and Measures (continued)

Information - Category - Measure Mapping		
Information Categories	**Measurable Concepts**	**Prospective Measures**
Product Quality	Functional Correctness	Defects Age of Defects Technical Performance Level
	Supportability-Maintainability	Time to Restore Cyclomatic Complexity
	Efficiency	Utilization Throughput Response Time
	Portability	Standards Compliance
	Usability	Operator Errors
	Dependability-Reliability	Mean Time to Failure
Process Performance	Process Compliance	Reference Maturity Rating Process Audit Findings
	Process Efficiency	Productivity Cycle Time
	Process Effectiveness	Defects Contained Defects Escaping Rework Effort Rework Components
Technology Effectiveness	Technology Suitability Technology Volatility	Requirements Coverage Baseline Changes
Customer Satisfaction	Customer Feedback	Satisfaction Ratings Award Fee
	Customer Support	Requests for Support Support Time

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