12th ICCRTS

Coalition Command and Control in the Networked Era

Axiomatic Design Approach for Designing Re-Configurable C4ISR Systems

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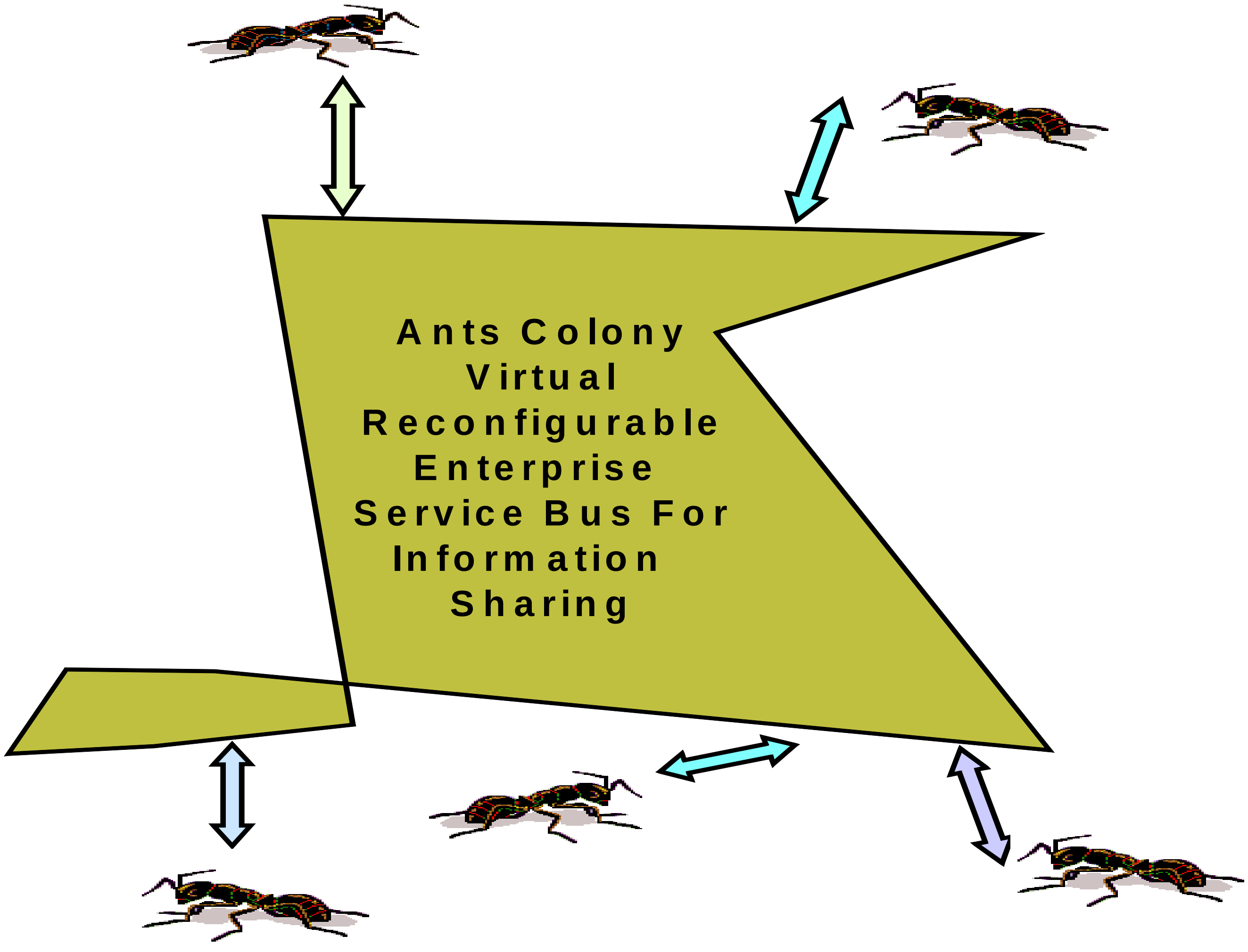
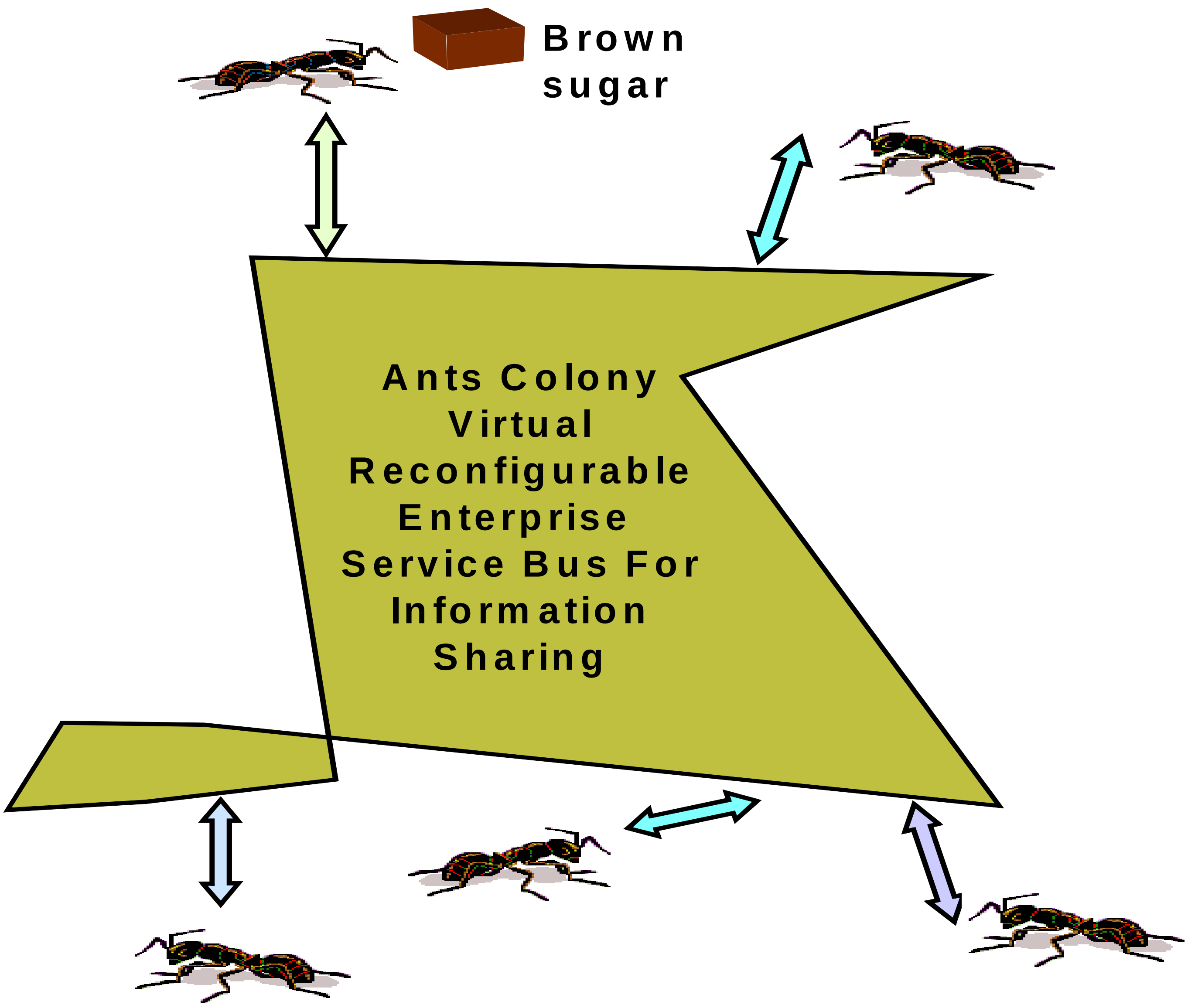
Topics: C2 Concepts, Theory, And Policy; Modeling and Simulation; C2 Technologies and Systems

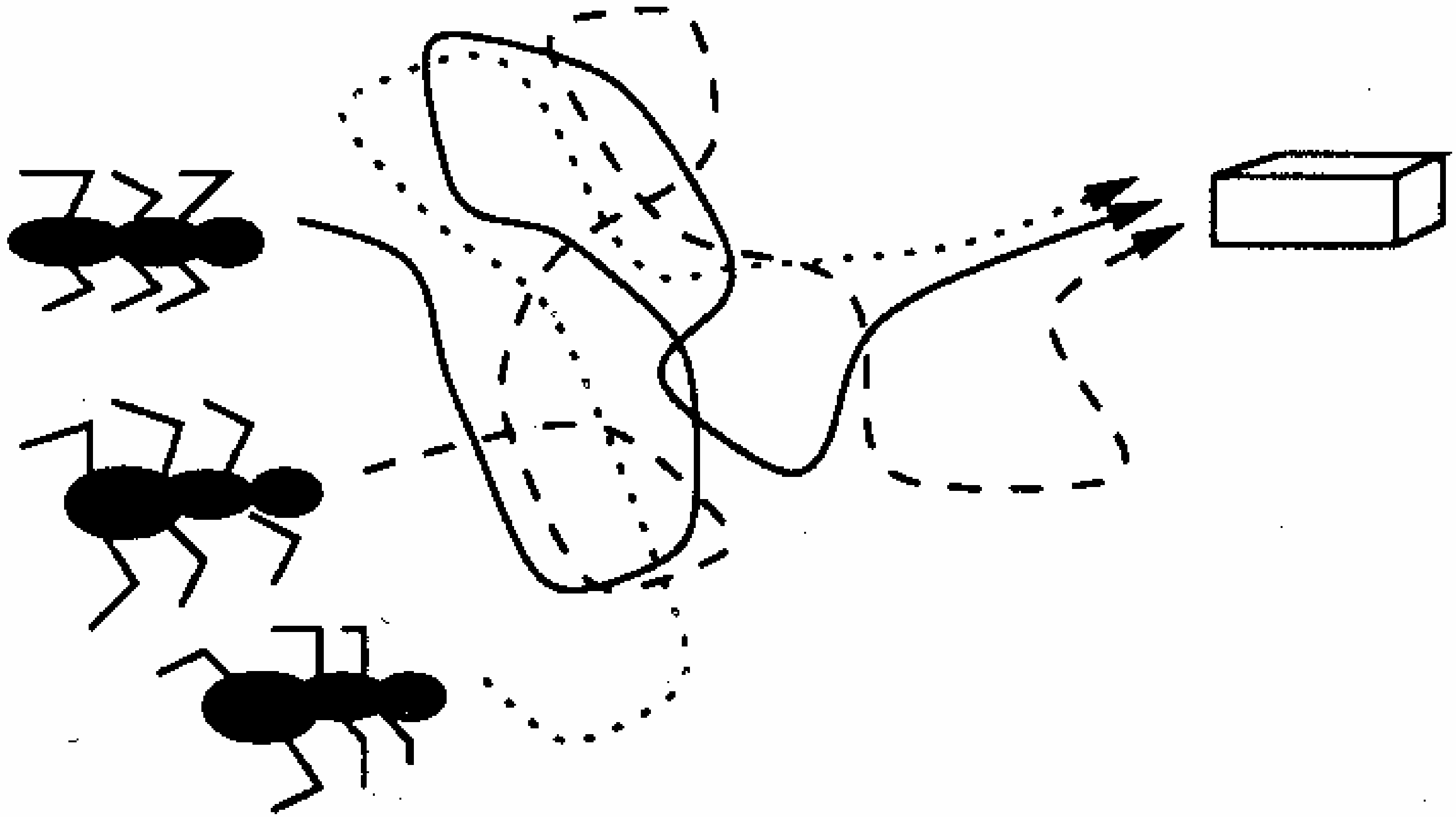
OVERVIEW

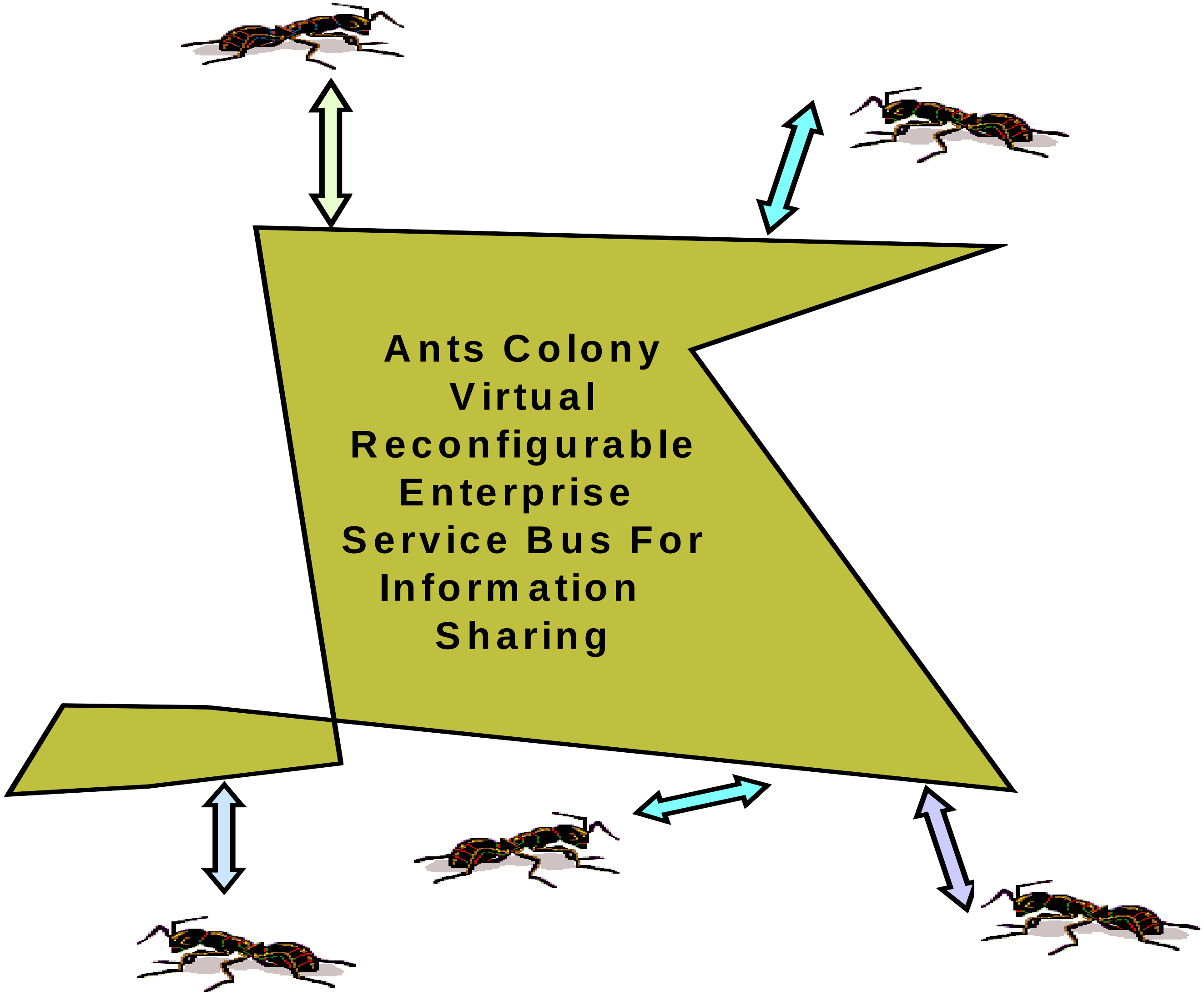
- DISCUSS ANTS COLONY AS AN EXAMPLE OF AN IDEAL NET-CENTRIC VALUE SYSTEM
- MAKE AN ANALOGY BETWEEN ANTS ADAPTIVE ECOSYSTEM AND DOD NET-CENTRIC WARFARE (NCW)
- DISCUSS THE ISSUES WITH DOD TRANSFORMATION OF CURRENT SYSTEMS-OF-SYSTEMS (SOS) TO NCW
- DISCUSS DODAF AND ITS ISSUES FOR C4ISR DESIGN
- DISCUSS PORTER'S VALUE SYSTEMS, AXIOMATIC THEORY, SERVICE-ORIENTED ARCHITECTURE (SOA)
- DISCUSS THE DESIGN OF A GENERIC C4ISR MODEL
- DISCUSS SUMMARY AND FUTURE POTENTIAL CAPABILITIES OF THE GENERIC C4ISR DESIGN MODEL
- QUESTIONS



COMMAND (BUSINESS GOAL OR MISSION) and CONTROL (GAME PLAN) FOR ANTS COLONY


Brown sugar
Ants Colony Virtual Reconfigurable Enterprise Service Bus For Information Sharing




Ants Colony
Virtual
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Enterprise
Service Bus For
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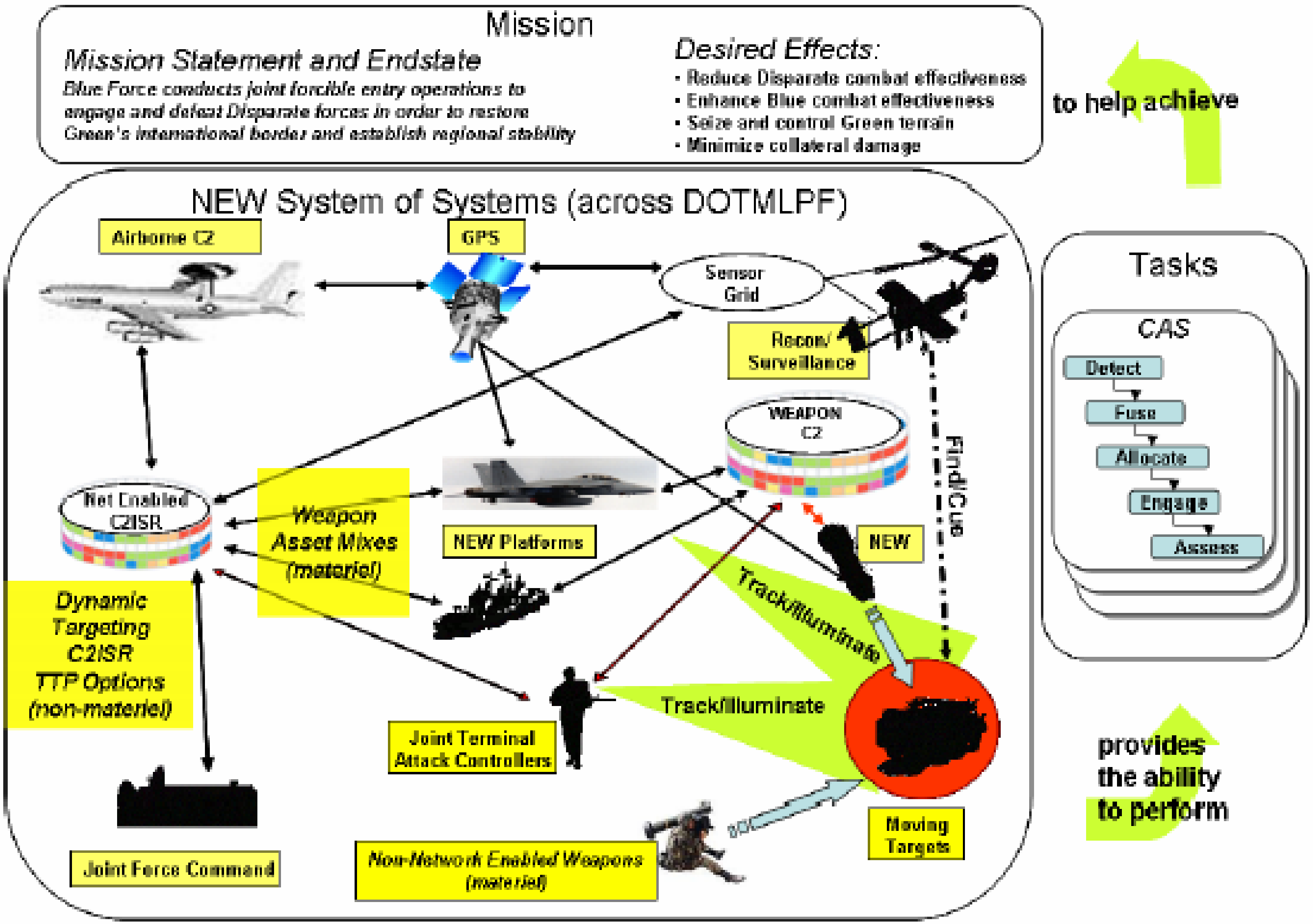
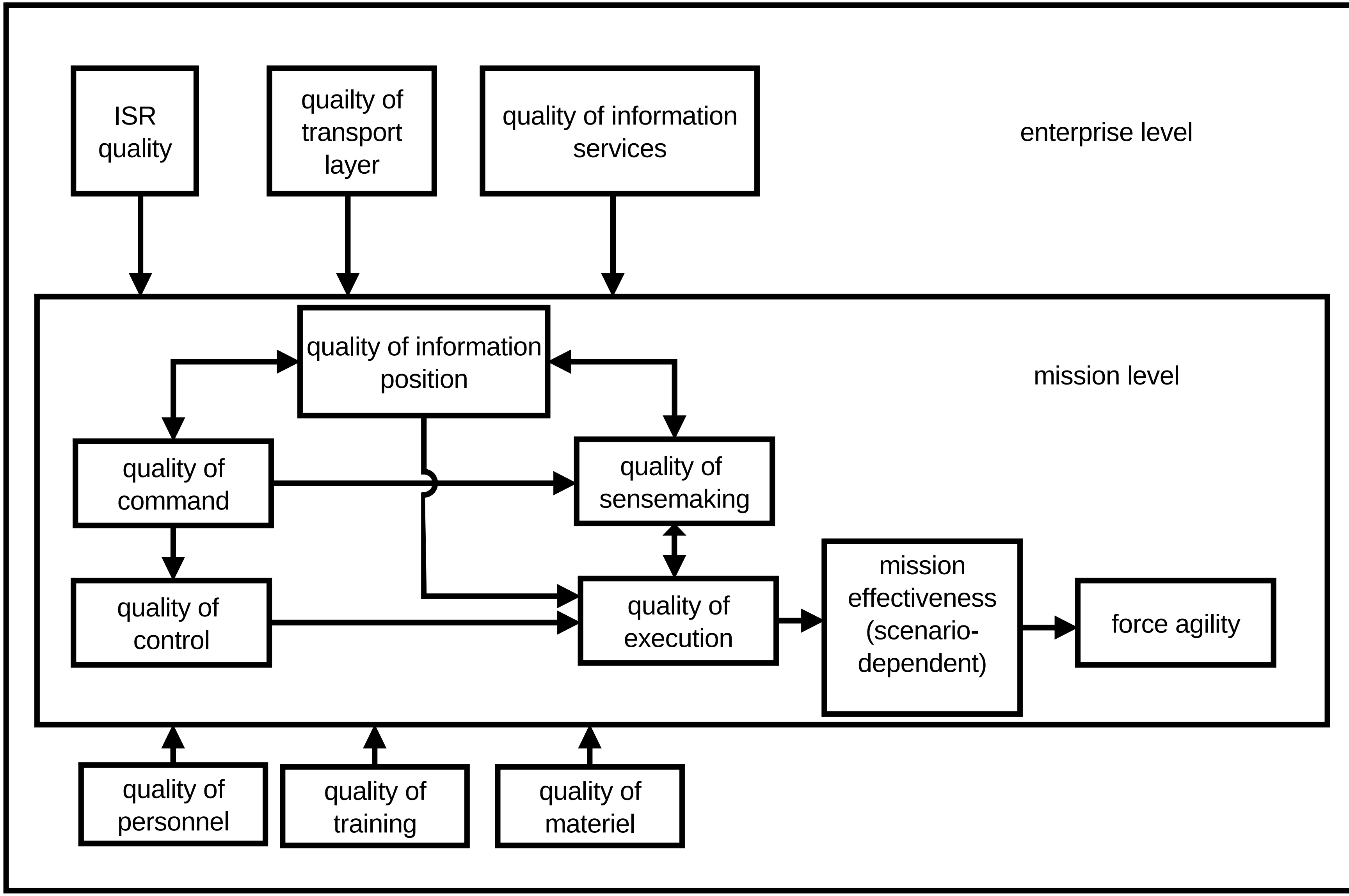

Mission
Mission Statement and Endstate
Blue Force conducts joint forcible entry operations to engage and defeat Disparate forces in order to restore Green's international border and establish regional stability
Desired Effects:
• Reduce Disparate combat effectiveness
• Enhance Blue combat effectiveness
• Seize and control Green terrain
• Minimize collateral damage
to help achieve
NEW System of Systems (across DOTMLPF)
Airborne C2
GPS
Sensor Grid
Recon/ Surveillance
WEAPON C2
Find/Cue
Net Enabled C2ISR
Weapon Asset Mixes (materiel)
NEW Platforms
NEW
Track/Illuminate
Dynamic Targeting C2ISR TTP Options (non-materiel)
Track/Illuminate
Joint Terminal Attack Controllers
Moving Targets
Joint Force Command
Non-Network Enabled Weapons (materiel)
Tasks
CAS
Detect
Fuse
Allocate
Engage
Assess
provides the ability to perform

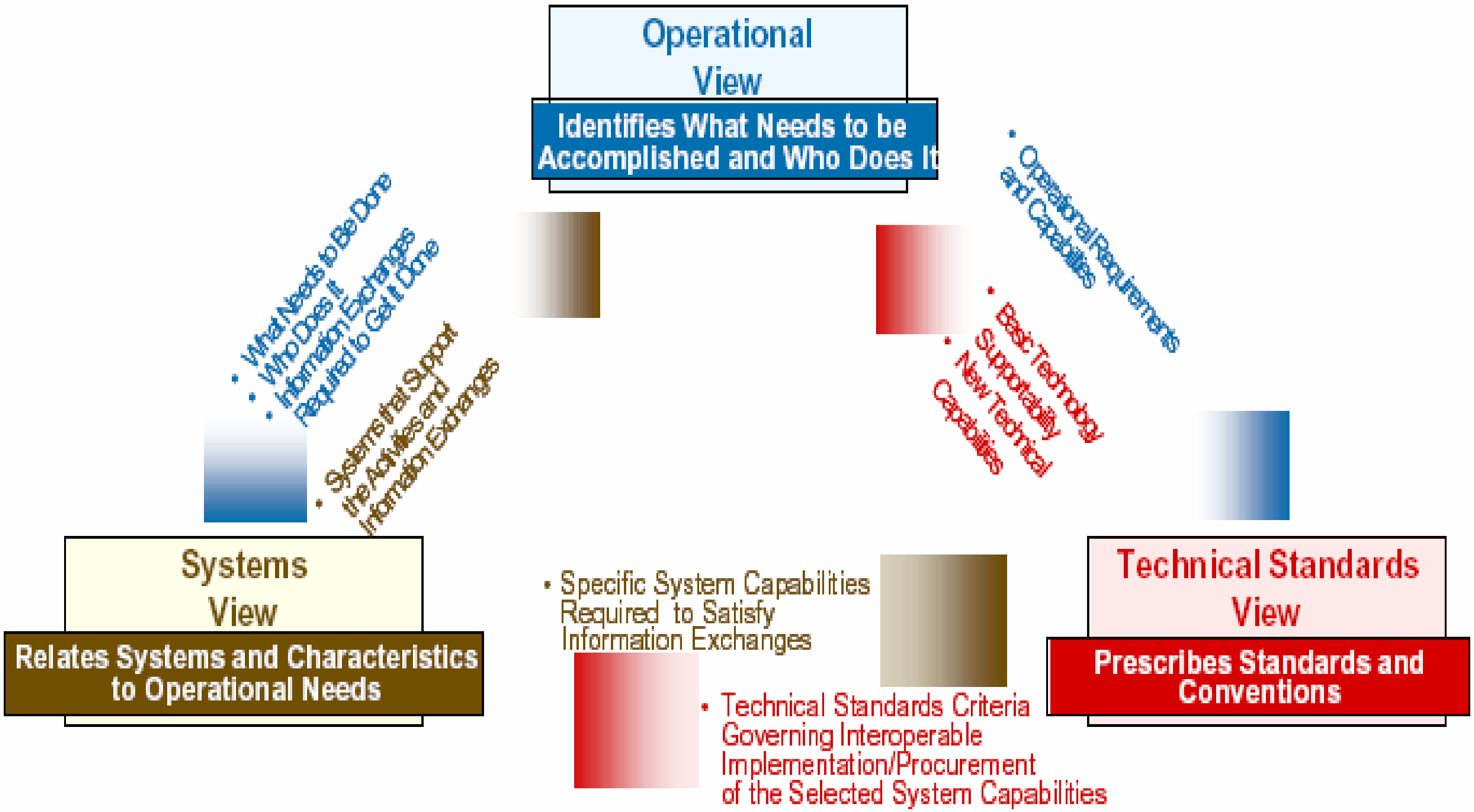

ISR quality
quailty of transport layer
quality of information services
enterprise level
quality of information position
mission level
quality of command
quality of sensemaking
quality of control
quality of execution
mission effectiveness (scenario-dependent)
force agility
quality of personnel
quality of training
quality of materiel

NET-CENTRIC WARFARE CONCEPT IS GREAT, BUT MAJOR ISSUES EXIST:

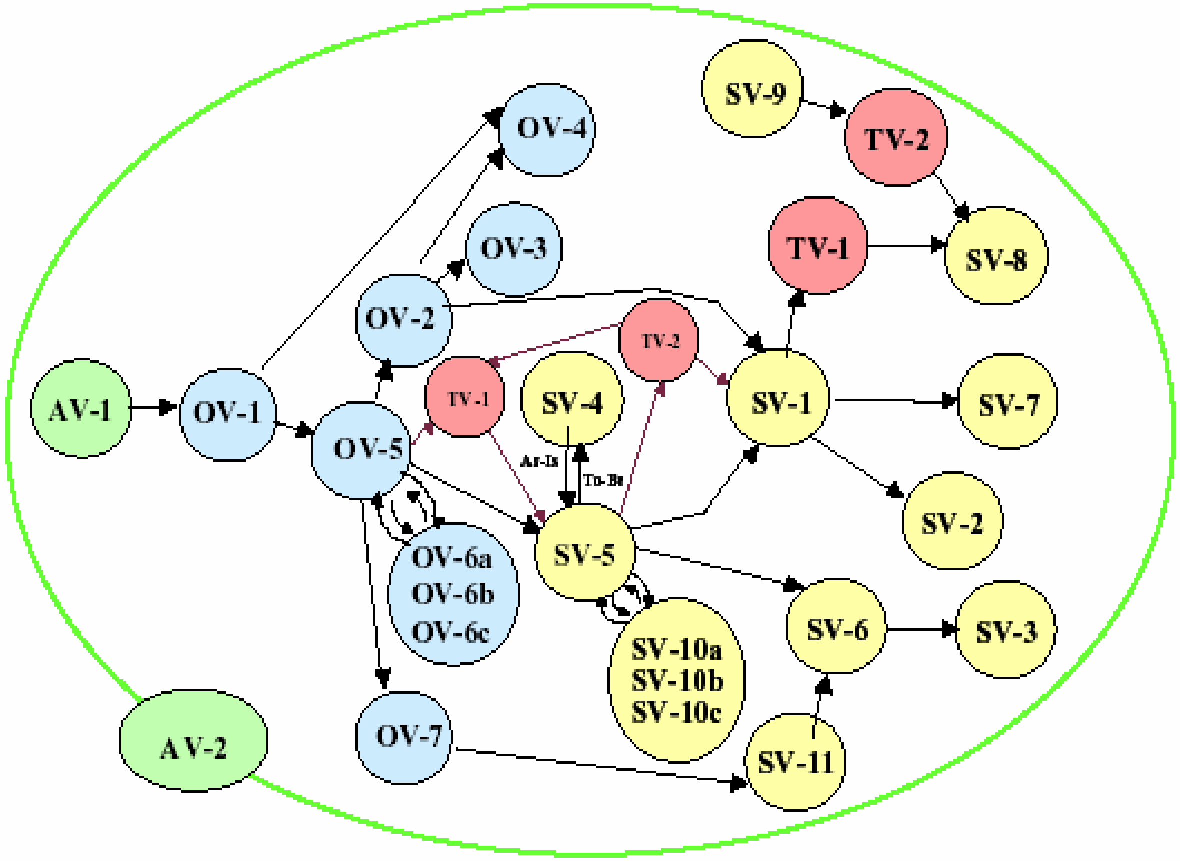
- **MANY DOD STOVE-PIPED SYSTEMS-OF-SYSTEMS EXIST WHICH ARE INTEROPERABLE, E.G., according to Strassmann [Anthes November 27 2006], DOD currently has 3,700 systems (excluding intelligence and war-fighting systems), including 174 supporting human resources in the U.S. Navy alone. Strassmann points out that most of those systems were built one at a time and most have their own communications and access methods, interfaces, data definitions and so on. Thus, integrating these separate systems is an enormous challenge.**

- **More importantly, these disparate systems are potential sources of cyber attacks – 3,700 points of vulnerability [Anthes November 27 2006].**

- **SOLUTION – USE DODAF TO INTEGRATE THEM! BUT DODAF ALSO HAS SOME ISSUES. LET US FIRST DISCUSS AN OVERVIEW OF DODAF, PORTER'S GENERIC VALUE SYSTEM MODEL, AXIOMATIC DESIGN OF SYSTEM, SYSTEMS-OF-SYSTEMS OR A PRODUCT, SERVICE-ORIENTED ARCHITECTURE BEFORE DODAF ISSUES.**

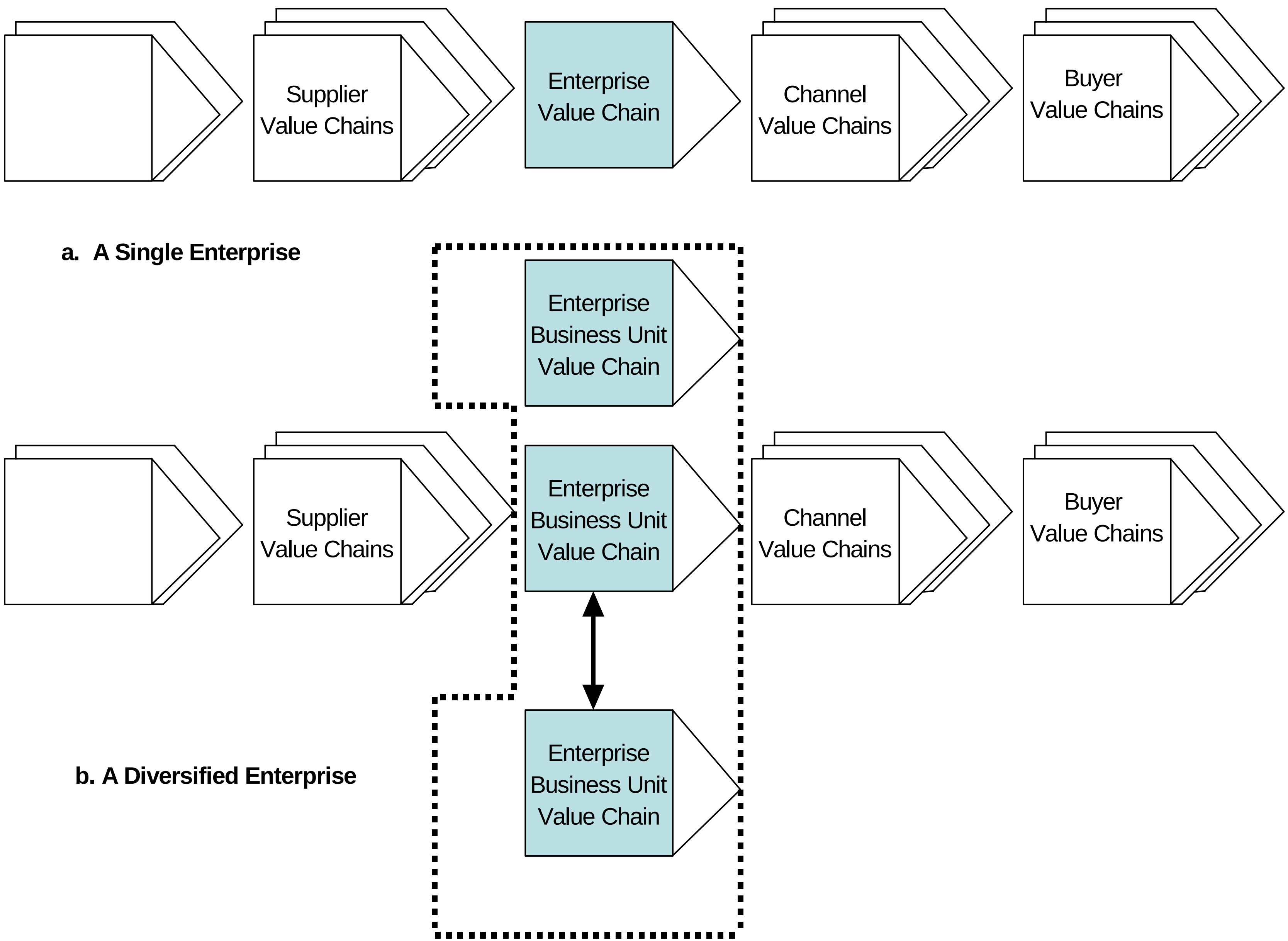

Operational View
Identifies What Needs to be Accomplished and Who Does It
• What Needs to Be Done
• Who Does It
• Information Exchanges Required to Get It Done
• Systems that Support the Activities and Information Exchanges
• Operational Requirements and Capabilities
• Basic Technology Supportability
• New Technical Capabilities
Systems View
Relates Systems and Characteristics to Operational Needs
Technical Standards View
Prescribes Standards and Conventions
• Specific System Capabilities Required to Satisfy Information Exchanges
• Technical Standards Criteria Governing Interoperable Implementation/Procurement of the Selected System Capabilities

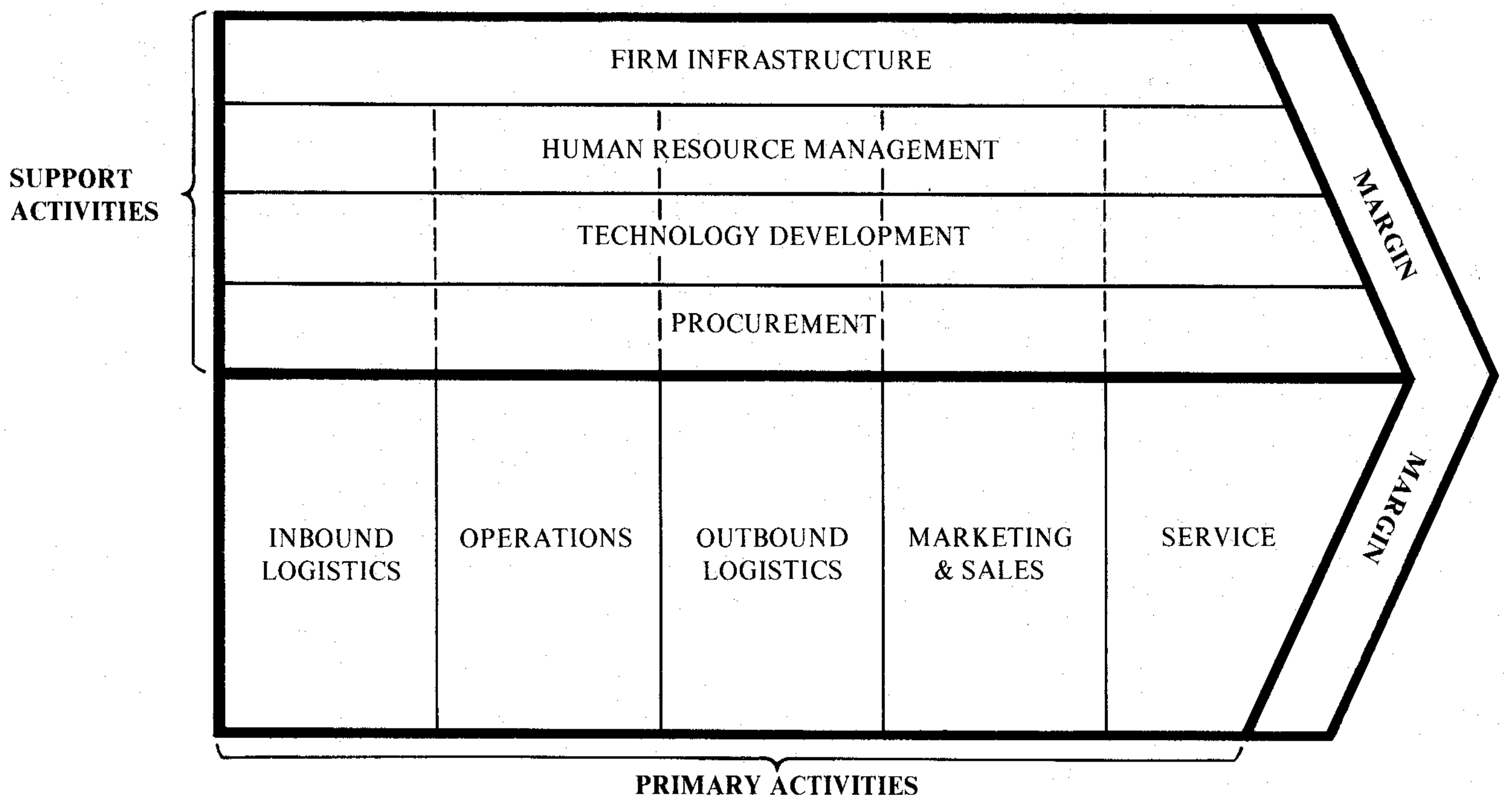
Applicable View	Framework Product	Framework Product Name	General Description
All Views	AV-1	Overview and Summary Information	Scope, purpose, intended users, environment depicted, analytical findings
All Views	AV-2	Integrated Dictionary	Architecture data repository with definitions of all terms used in all products
Operational	OV-1	High-Level Operational Concept Graphic	High-level graphical/textual description of operational concept
Operational	OV-2	Operational Node Connectivity Description	Operational nodes, connectivity, and information exchange needlines between nodes
Operational	OV-3	Operational Information Exchange Matrix	Information exchanged between nodes and the relevant attributes of that exchange
Operational	OV-4	Organizational Relationships Chart	Organizational, role, or other relationships among organizations
Operational	OV-5	Operational Activity Model	Capabilities, operational activities, relationships among activities, inputs, and outputs; overlays can show cost, performing nodes, or other pertinent information
Operational	OV-6a	Operational Rules Model	One of three products used to describe operational activity—identifies business rules that constrain operation
Operational	OV-6b	Operational State Transition Description	One of three products used to describe operational activity—identifies business process responses to events
Operational	OV-6c	Operational Event-Trace Description	One of three products used to describe operational activity—traces actions in a scenario or sequence of events
Operational	OV-7	Logical Data Model	Documentation of the system data requirements and structural business process rules of the Operational View
Systems	SV-1	Systems Interface Description	Identification of systems nodes, systems, and system items and their interconnections, within and between nodes
Systems	SV-2	Systems Communications Description	Systems nodes, systems, and system items, and their related communications lay-downs
Systems	SV-3	Systems-Systems Matrix	Relationships among systems in a given architecture; can be designed to show relationships of interest, e.g., system-type interfaces, planned vs. existing interfaces, etc.
Systems	SV-4	Systems Functionality Description	Functions performed by systems and the system data flows among system functions
Systems	SV-5	Operational Activity to Systems Function Traceability Matrix	Mapping of systems back to capabilities or of system functions back to operational activities
Systems	SV-6	Systems Data Exchange Matrix	Provides details of system data elements being exchanged between systems and the attributes of that exchange
Systems	SV-7	Systems Performance Parameters Matrix	Performance characteristics of Systems View elements for the appropriate time frame(s)
Systems	SV-8	Systems Evolution Description	Planned incremental steps toward migrating a suite of systems to a more efficient suite, or toward evolving a current system to a future implementation
Systems	SV-9	Systems Technology Forecast	Emerging technologies and software/hardware products that are expected to be available in a given set of time frames and that will affect future development of the architecture
Systems	SV-10a	Systems Rules Model	One of three products used to describe system functionality—identifies constraints that are imposed on systems functionality due to some aspect of systems design or implementation
Systems	SV-10b	Systems State Transition Description	One of three products used to describe system functionality—identifies responses of a system to events
Systems	SV-10c	Systems Event-Trace Description	One of three products used to describe system functionality—identifies system-specific refinements of critical sequences of events described in the Operational View
Systems	SV-11	Physical Schema	Physical implementation of the Logical Data Model entities, e.g., message formats, file structures, physical schema
Technical	TV-1	Technical Standards Profile	Listing of standards that apply to Systems View elements in a given architecture
Technical	TV-2	Technical Standards Forecast	Description of emerging standards and potential impact on current Systems View elements, within a set of time frames



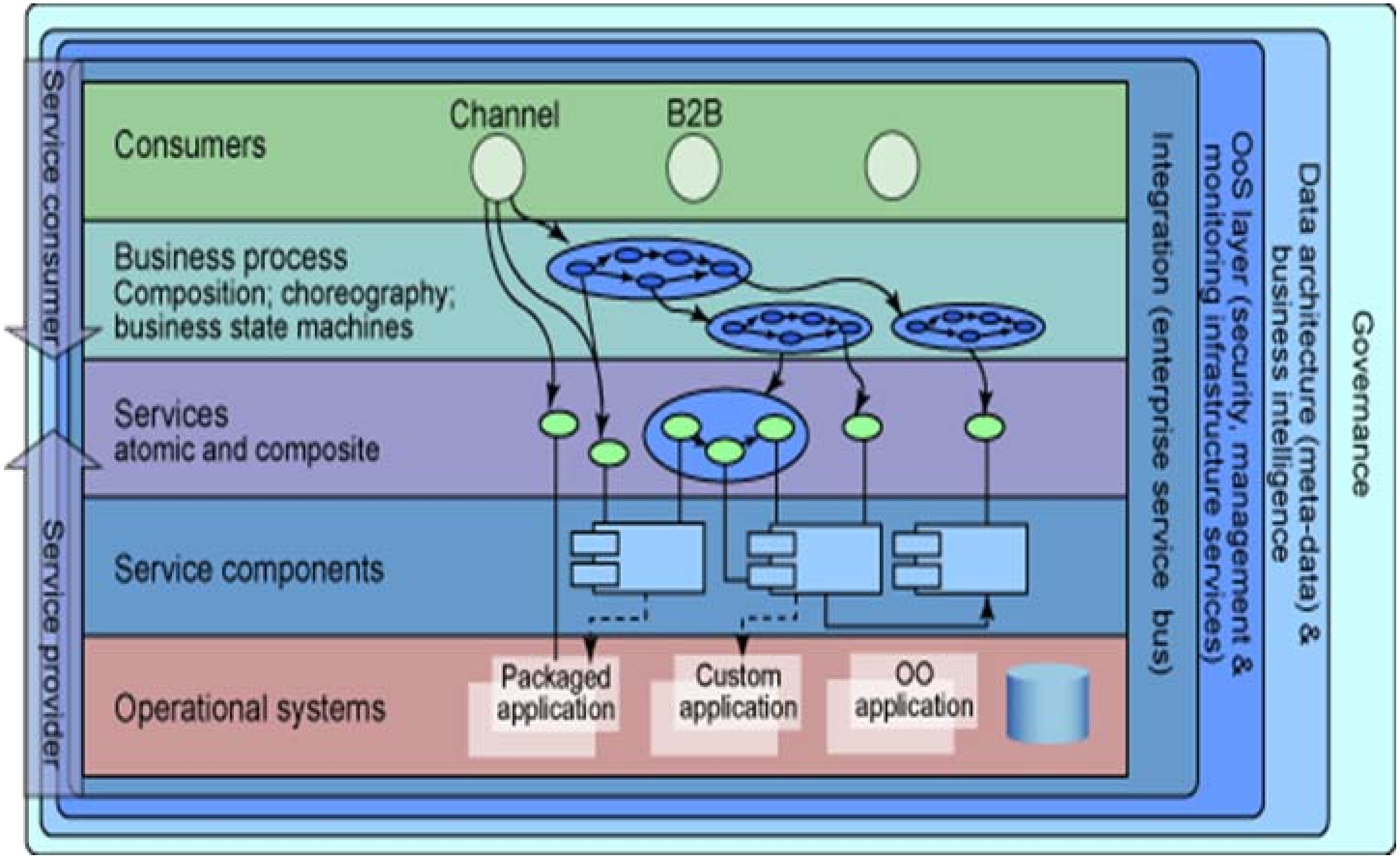
SV-9
TV-2
OV-4
OV-3
TV-1
SV-8
OV-2
TV-2
AV-1
OV-1
TV-1
SV-4
SV-1
SV-7
OV-5
SV-2
OV-6a
OV-6b
OV-6c
SV-5
SV-10a
SV-10b
SV-10c
SV-6
SV-3
AV-2
OV-7
SV-11

LEAF OPERATIONAL ACTIVITY MODELS (OV-5S) GUIDED BY GLOBAL OPERATIONS

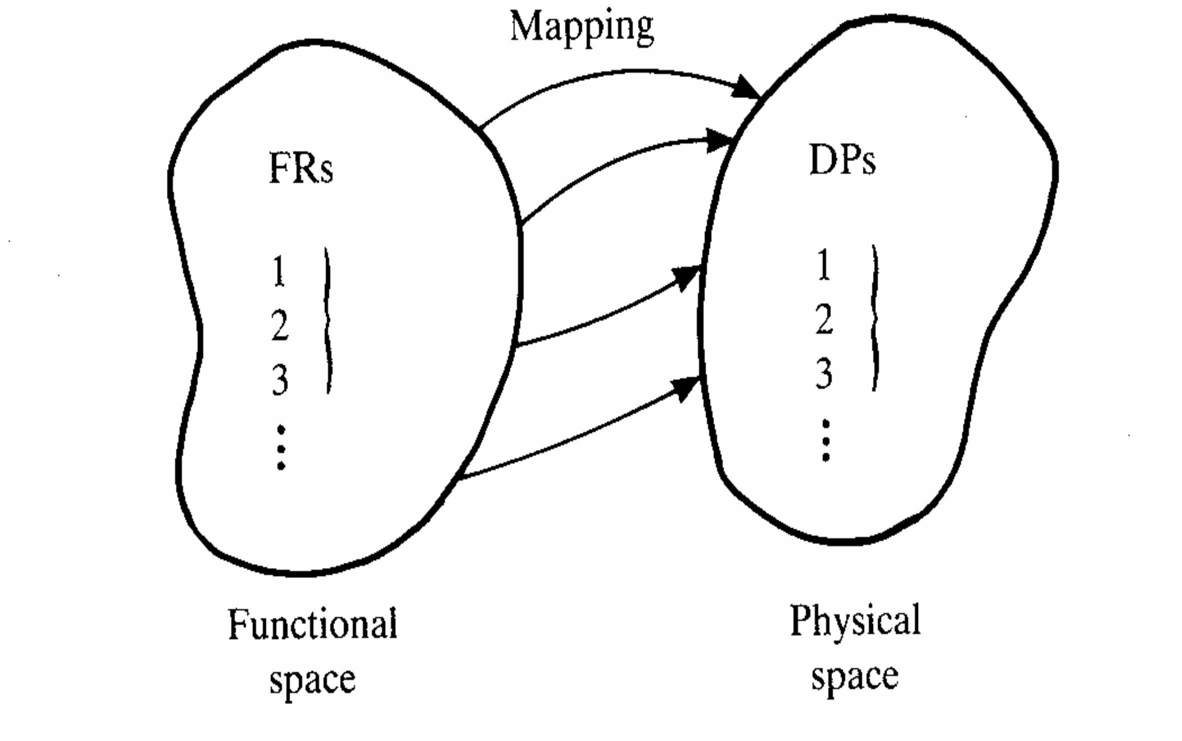

Supplier
Value Chains
Enterprise
Value Chain
Channel
Value Chains
Buyer
Value Chains
a. A Single Enterprise
Enterprise
Business Unit
Value Chain
Supplier
Value Chains
Enterprise
Business Unit
Value Chain
Channel
Value Chains
Buyer
Value Chains
b. A Diversified Enterprise
Enterprise
Business Unit
Value Chain



SUPPORT ACTIVITIES
FIRM INFRASTRUCTURE
HUMAN RESOURCE MANAGEMENT
TECHNOLOGY DEVELOPMENT
PROCUREMENT
MARGIN
INBOUND LOGISTICS
OPERATIONS
OUTBOUND LOGISTICS
MARKETING & SALES
SERVICE
MARGIN
PRIMARY ACTIVITIES



SOA = INTEROPERABILITY + AGILITY (FOR DESIGN OF ANY INTEGRATED VALUE SYSTEMS) WITH GOVERNANCE TO ELIMINATE STOVE-PIPED SYSTEMS-OF-SYSTEMS (SOS)



$$\{FR_i\} = [DM]\{DP_i\}$$ **…. BASIC DESIGN EQUATION**

$\{FR_i\} =$ the vector that represents the functional requirements in the functional domain

$\{DP_i\} =$ the vector that represents the design parameters in the physical domain

$[DM] =$ the design matrix that relates $\{FR_i\}$ to $\{DP_i\}$

$$[DM] = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1n} \\ A_{21} & A_{22} & \cdots & A_{2n} \\ . & . & & . \\ . & . & & . \\ . & . & & . \\ A_{m1} & A_{m2} & \cdots & A_{mn} \end{bmatrix}$$

@ t = 0

$$\{FR\}_0 = \{FR_1, \; FR_5, \; FR_7, \; FR_m\}$$

$$\{DP\}_0 = \{DP_1, \; DP_5, \; DP_7, \; DP_m\}$$

@ t = T_1

$$\{FR\}_1 = \{FR_3, \; FR_5, \; FR_8, \; FR_z\}$$

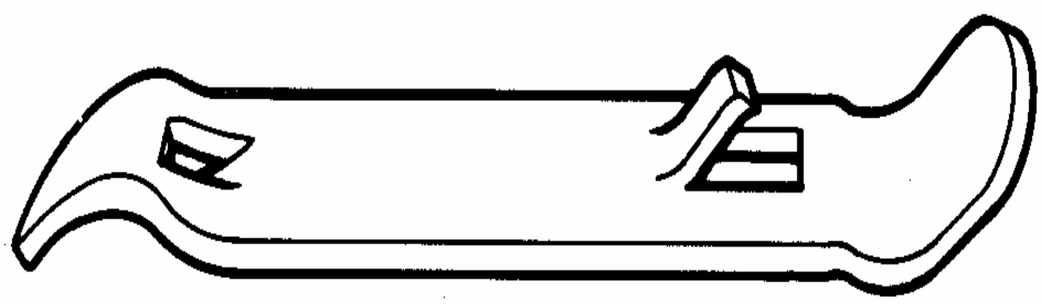
$$\{DP\}_1 = \{DP_3, \; DP_5, \; DP_8, \; DP_z\}$$

Figure below shows can and bottle opener. This device satisfies two objectives or functional requirements (FRs). The FRs are fulfilled by the following physical solutions or design parameters (DPs):

Goal 1 (FR1): Open cans; DP1: Can Opener

Goal 2 (FR2): Opens bottles; DP2: Bottle Opener

If the requirements are not to perform these two functions simultaneously, then this physically integrated device satisfies two independent goals or functional requirements (FRs). Otherwise *coupling* occurs if both goals must be concurrently met with the same device. We can use COROLLARY 1 (please see Slide 20) to redesign the device to eliminate coupling, while fulfilling both FRs simultaneously, with both DPs.



Among the corollaries and theorems derived from AXIOM 1 and AXIOM 2, the following four corollaries and a theorem, are essential for designing C4ISR, namely [Suh 1990; Suh 2001]:

Corollary 1: Decoupling of Coupled Design: Decouple or separate parts or aspects of a solution if FRs are coupled or become interdependent in the proposed designs.

Corollary 2: Minimization of FRs: Minimize the number of functional requirements and constraints. Strive for maximum simplicity in overall design or the utmost simplicity in physical and functional characteristics.

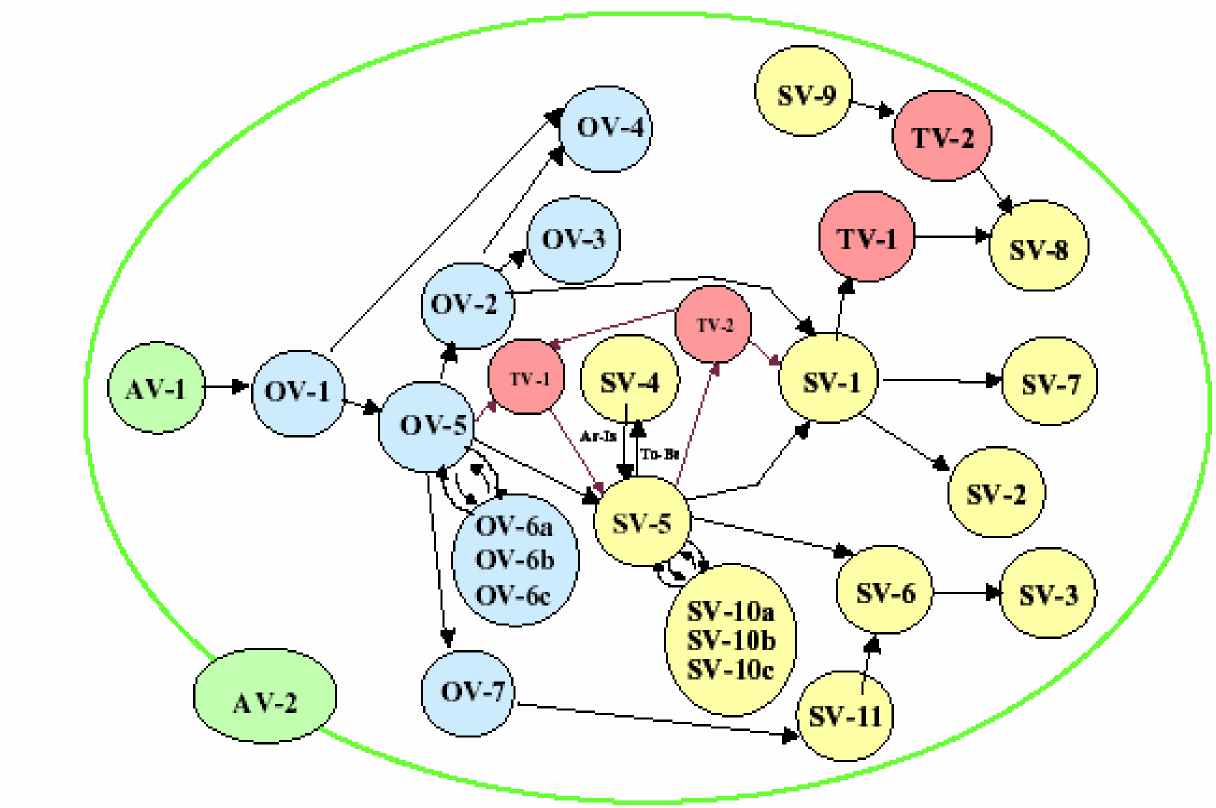
***Corollary 3: Integration of Physical Parts: Integrate design features into a single physical process, device, or system when FRs can be independently satisfied in the proposed solution*.**

Corollary 4: Use of Standardization: Use standardized or interchangeable parts if the use of these parts is consistent with the FRs and constraints.

THEOREM M2 (Large System with Several Subunits) When a large (e.g., organization) consists of several subunits, each unit must satisfy independent subsets of FRs so as to eliminate the possibility of creating a resource-intensive system or a coupled design for the entire system.

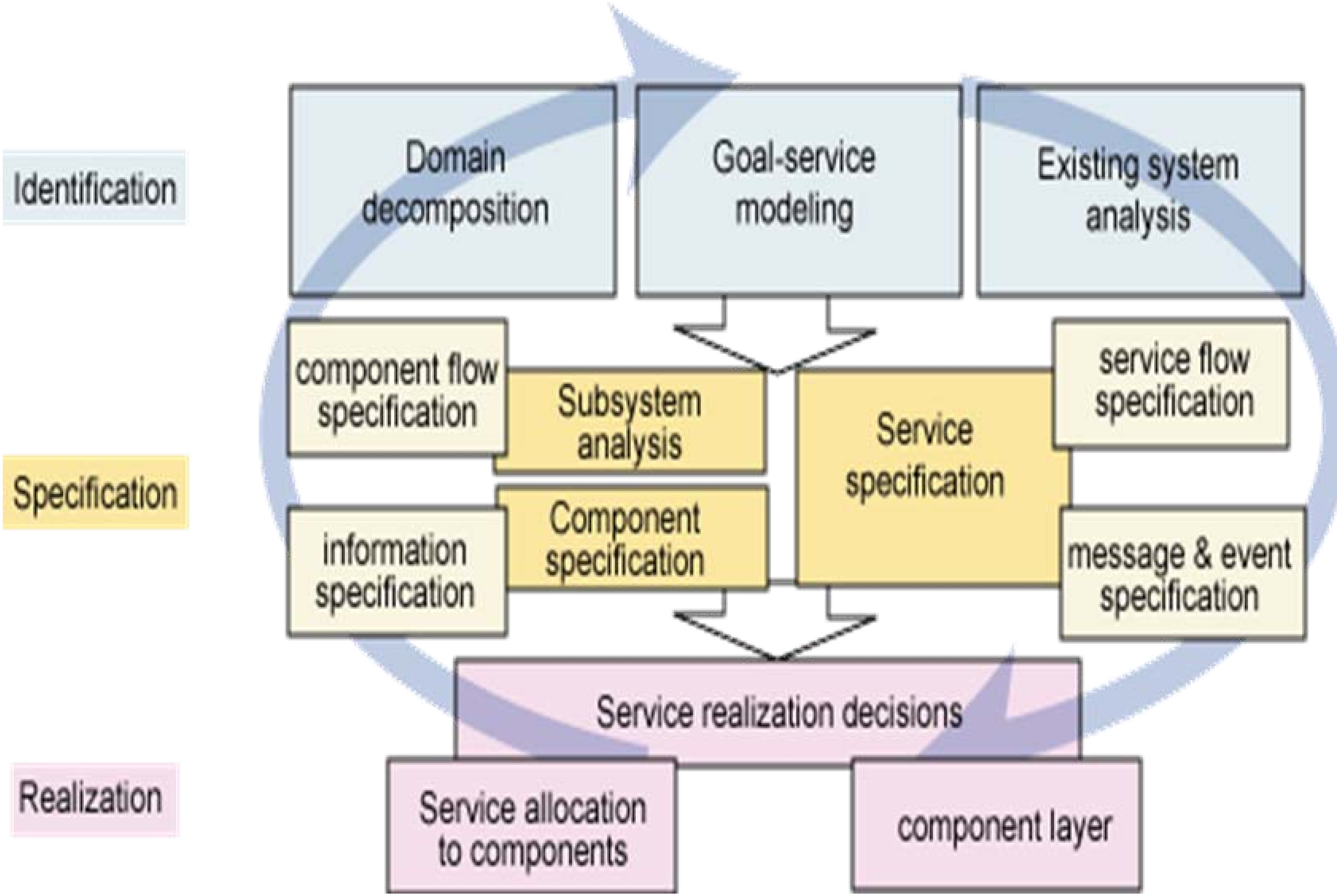
$$M_k = \sum_{j=1}^{j=k} \frac{\partial FR_k}{\partial DP_j} \frac{DP_j}{DP_k}$$

Generalized equation for creating a module-diagram, which shows the design structure of the SOS such as C4ISR SOS.



<u>DODAF BASIC ISSUE</u>: FOR EACH NEW DOD MISSION (GLOBAL FRs) WITH DIFFERENT MISSION THREADS (OV-5S) --OPERATIONAL ACTIVITY MODELS (EDGE FRs) --WE MUST CREATE A NEW OV-1. OTHERWISE, THE NEW OV-5 WILL NO LONGER SUPPORT THE OLD OV-1. THAT IS, COUPLING WILL OCCUR BETWEEN THE NEW OV-5 AND THE OLD OV-1.

BUT SOA SAYS THAT WE SHOULD USE THE SAME SERVICE-BASED VALUE SYSTEM (OV-1– SLIDE 13 OR 24) FOR EVERY NEW OV-5. WE JUST ONLY ENSURE THAT COROLLARY 4 IS NOT VIOLATED!



CREATING THE SOA-BASED RE-CONFIGURABLE C4ISR

LEAF OPERATIONAL ACTIVITY MODELS (OV-5s) GUIDED BY GLOBAL OPERATIONS

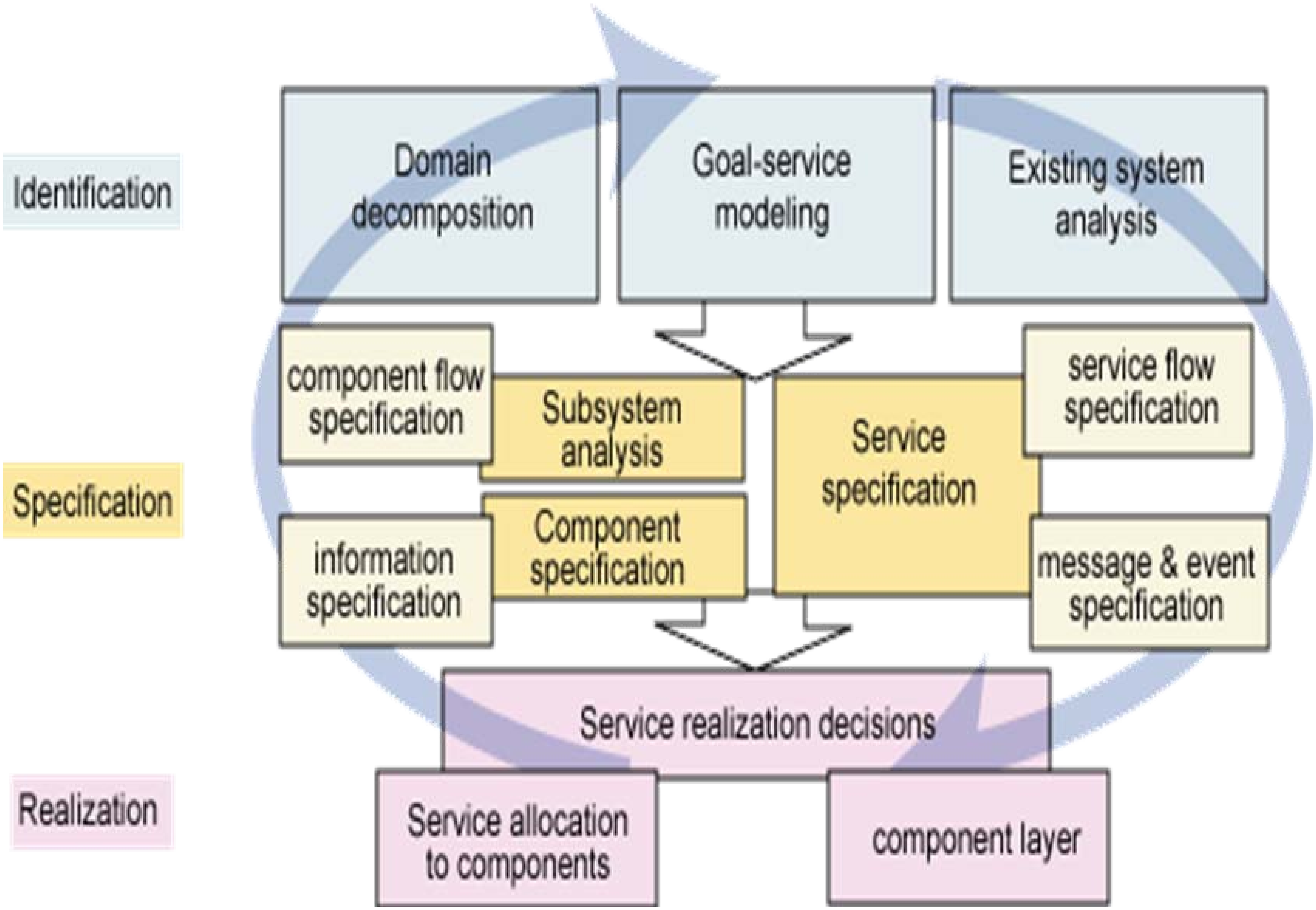
PROCESSES	Customer	Budget	Financial	Vendor	Procurements	Materials inventory	Fin. goods inventory	Orders	Cost	Sales	Sales territory	Payments	Planning	Employee	Salaries	Facilities	Work in progress	Machine load	Open requirement	Shop floor routings	Product	Product design	Parts master	Bill of materials
	SUBJECT DATABASES																							
Market analysis	R									R	R		R								R			
Product range review									R				R											
Sales forecasting	R	C								R	R		C								R			
Financial planning		R							R				C											
Capital acquisition		R	C										R											
Funds management		R	R																					
Product design													R								C	C	C	
Product pricing		R							R												C	R		
Product spec. maint.																					R		C	C
Materials requirements				R															C		R		R	R
Purchasing				C	C																R		R	
Receiving				R	R	R															R		R	
Inventory control						C											R							
Quality control					C																			
Capacity planning				R												R		C	R	R				
Plant scheduling																R	C	R		R	R			
Workflow layout																C				C	R			
Materials control				R													R				R			R
Sizing and cutting																		R		C	R			R
Machine operations																		R		C				
Territory management	C							R			R													
Selling										C	C													
Sales administration								R			R													
Customer relations	R							R		R														
Finished stock control							C										R				R			
Order servicing	R							C													R			
Packing								R													R			
Shipping																					R			
Creditors and debtors	R			R								R												
Cash flow	R			R	R			R	R			R			R		R							
Payroll												C		R	R									
Cost accounting					R				C			C												R
Budget planning		C	R						R	R			R				R							
Profitability analysis									R	R														
Personnel planning			R											C	C									
Recruiting														R	R									
Compensation policy			R											R	R									


Achieve the lowest operational cost, perfect quality, and shortest cycle time for executing any SVS.
Create information-based model for each supplier value chain.
Create information-based model for the enterprise value chains.
Create information-based model for each channel's value chain.
Create information-based model for each buyer's value chain.

PROCESSES	SUBJECT DATABASES																							
	Planning	Budget	Financial	Product	Product design	Parts master	Bill of materials	Open requirements	Vendor	Procurements	Materials inventory	Machine load	Work in progress	Facilities	Shop floor routings	Customer	Sales	Sales territory	Fin. goods inventory	Orders	Payments	Cost	Employee	Salaries
Market analysis	R			R												R	R	R						
Product range review	R																					R		
Sales forecasting	C	C		R												R	R	R						
Financial planning	C	R																				R		
Capital acquisition	R	R	C																					
Funds management		R	R																					
Product design	R			C	C	C																		
Product pricing		R		C	R																	R		
Product spec. maint.				R		C	C																	
Materials requirements				R		R	R	C	R															
Purchasing				R		R			C	C														
Receiving				R		R			R	R	R													
Inventory control											C		R											
Quality control										C														
Capacity planning								R	R			C		R	R									
Plant scheduling				R								R	C	R	R									
Workflow layout				R										C	C									
Materials control				R			R		R				R											
Sizing and cutting				R			R					R			C									
Machine operations												R			C									
Territory management																C		R		R				
Selling																	C	C						
Sales administration																		R		R				
Customer relations																R	R			R				
Finished stock control				R									R						C					
Order servicing				R												R				C				
Packing				R																R				
Shipping				R																				
Creditors and debtors									R							R					R			
Cash flow									R	R			R			R				R	R	R		R
Payroll																					C		R	R
Cost accounting							R			R											C	C		
Budget planning	R	C	R										R				R					R		
Profitability analysis																	R					R		
Personnel planning			R																				C	C
Recruiting																							R	R
Compensation policy			R																				R	R

LEAF ACTIVITIES	Employee	Contact Employee	Applicant	HR Compensation Regs, Plans, etc.	HR Benefits Regs & Plans	HR Staffing Requirements & Plans	Job Requisition	Stockholder	Boardmember	Misc. Contacts/VIPs	Financial Plans	Accounting Regs, Practices	Ledger Accounts	Customer Purchase Order/Invoice	Customer Payments	Other Invoice
	ENTITY TYPES															
Evaluate Financial Proposals																
Estimate Near - Term Earnings														R		
Prepare Budget	R	R		R	R						C	R	U			
Receive Funds												R		R	C	U
Pay Funds	R											R				
Report Finances	R											R	U	R	R	R
Administer Taxes												R	R		R	R
Maintain Financial Reg, Policies											R	U				
Audit Finances												R	R		R	R
Manage Financial Investments								C				R				
Plan Human Resources	R	R				U	U		R		R					
Acquire Personnel	C	C	C			R	R		U							
Position People in Jobs			R			R	U		R							
Terminate/Retire People	U	U							U							
Plan Career Paths	U			R	R	R										
Develop Skills/Motivation	U	U			R	R										
Manage Individual Emp Relations	U	U			R											
Manage Benefits Programs					C											
Comply with Govt HR Regulations	R			R												
Maintain HR Regs, Policies				C		C										

LEAF ACTIVITIES	ENTITY TYPES: Financial Plans	Ledger Accounts	Customer Payments	Other Invoice	Accounting Regs, Practices	Stockholder	HR Staffing Requirements & Plans	Job Requisition	Contact Employee	Employee	Boardmember	Applicant	HR Benefits Regs & Plans	Misc. Contacts/MPs	Customer Purchase Order/Invoice	HR Compensation Regs, Plans, etc.
Evaluate Financial Proposals																
Estimate Near - Term Earnings															R	
Prepare Budget	C	U			R				R	R			R			R
Receive Funds			C	U	R										R	
Pay Funds					R					R						
Report Finances		U	R	R	R					R					R	
Administer Taxes		R	R	R	R											
Maintain Financial Reg, Policies	R				U											
Audit Finances		R	R	R	R											
Manage Financial Investments					R	C										
Plan Human Resources	R						U	U	R	R	R					
Acquire Personnel							R	R	C	C	U	C				
Position People in Jobs							R	U			R	R				
Terminate/Retire People									U	U	U					
Plan Career Paths							R			U			R			R
Develop Skills/Motivation							R		U	U			R			
Manage Individual Emp Relations									U	U			R			
Manage Benefits Programs													C			
Comply with Govt HR Regulations										R						R
Maintain HR Regs, Policies							C									C



CREATING THE SOA-BASED RE-CONFIGURABLE C4ISR

MATERIALS

- PURCHASING (1)
  - CREATE REQUISITION (A) *
  - SUPPLIER INFORMATION
    - RECORD SUPPLIER PERFORMANCE DATA (B) *
    - ANALYZE SUPPLIER PERFORMANCE (C) *
    - SELECT SUPPLIER (D) *
  - CREATE PURCHASE ORDER (E) *
  - CANCEL PURCHASE ORDER (F) *
  - FOLLOW UP DELIVERY (G) *
  - EXCEPTION PROCESSING
    - CREATE SPECIAL ORDER (H) *
    - SUPPLIER NONDELIVERY
      - TERMINATE ORDER (I) *
      - CREATE NEW ORDER (J) *
  - CREATE INFORMATION FOR ACCOUNTS PAYABLE (K) *
- RECEIVING

Let *PURCHASING (1)* represent the *Service component* for the *Purchasing Process*.
Let 2 represent the fine-grained service for *CREATE REQUISITION*.
Let 3 represent the fine-grained service for *RECORD SUPPLIER PERFORMANCE DATA*.
Let 4 represent the fine-grained service for *ANALYZE SUPPLIER PERFORMANCE*.
Let 5 represent the fine-grained service for *SELECT SUPPLIER*.
Let $6 = 2 \cap 3 \cap 4 \cap 5$.

where, the symbol $\cap$ represents the logical symbol for union of services.

Let 7 represent the fine-grained service for *CREATE PURCHASE ORDER*.
Let 8 represent the fine-grained service for *CANCEL PURCHASE ORDER*.
Let 9 represent the fine-grained service for *FOLLOW UP DELIVERY*.
Let 10 represent the fine-grained service for *CREATE INFORMATION FOR ACCOUNTS PAYABLE*.
Let 11 represent the fine-grained service for *CREATE SPECIAL ORDER*.
Let 12 represent the fine-grained service for *TERMINATE ORDER*.
Let 13 represent the fine-grained service for *CREATE NEW ORDER*.
Let $14 = 12 \cap 13$

For normal purchase order processing, the *Service component* for *PURCHASING (1)* can be logically expressed as follows:

PURCHASING (1) $= 6 \cap 7 \cap 9 \cap 10$

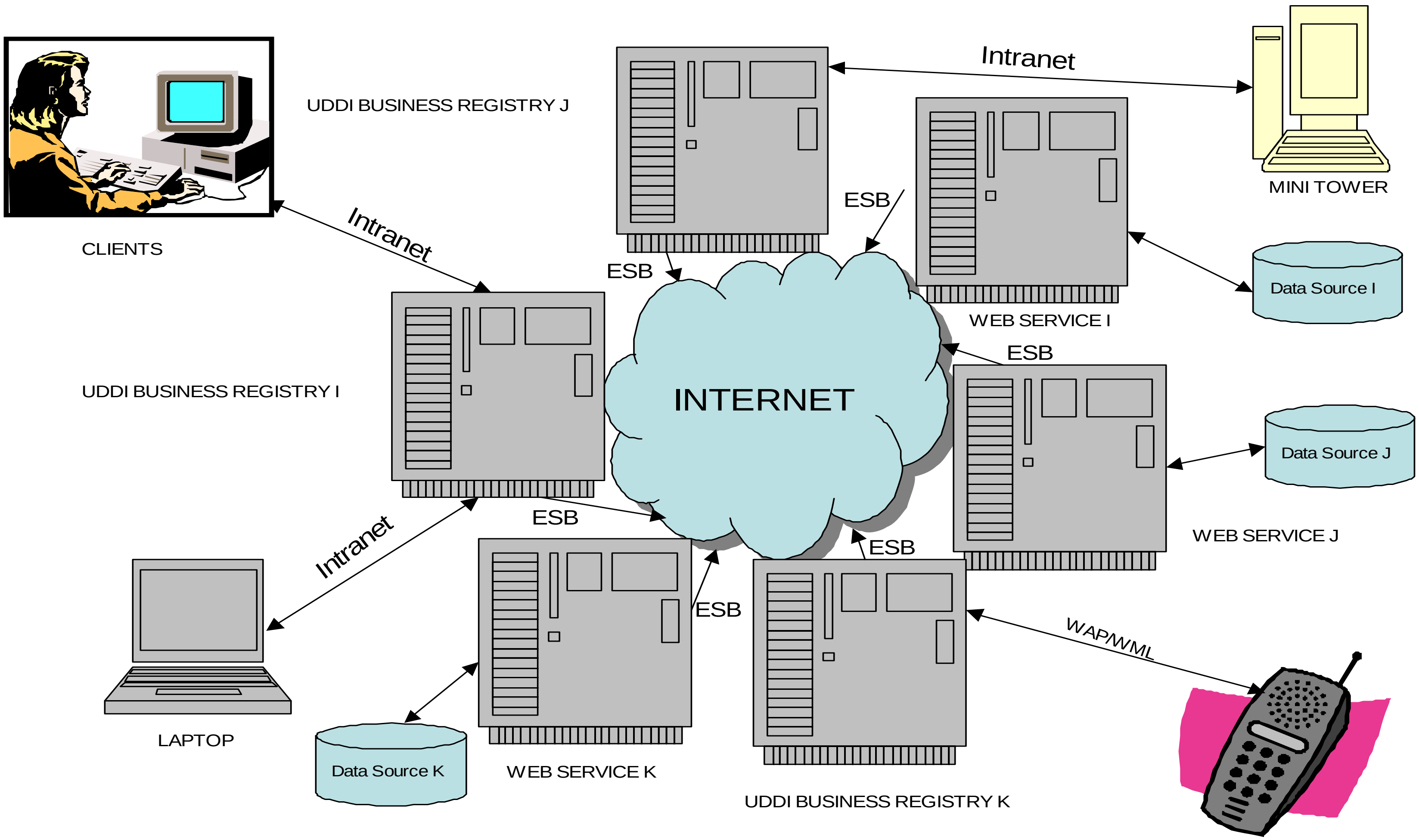
If the purchase order is cancelled, only the fine-grained service, designated as 8, will be executed. As noted before, to eliminate *Death path elimination*, BPEL will ensure that all process flow paths are completed before final execution of the fine-grained service is completed [Girault et al 2003; Havey 2005].

For special order processing (without non-delivery of the purchase order), *Service component* for *PURCHASING (1)* can be logically expressed as follows:

PURCHASING (1) = $6 \cap 11 \cap 10$

For special order processing which involves creating a new order to replace a non-delivery order, *Service component* for *PURCHASING (1)* can be logically expressed as follows:

PURCHASING (1) = $6 \cap 14 \cap 10$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SUMMARY AND FUTURE POTENTIAL CAPABILITIES

The proposed generic model provides potential capabilities for an experimental scientific research test bed in the on-going research activities on ***Power to the Edge***, such as Interoperability and Agility and more importantly as a test bed for creating integrated SOS for the Department of Homeland Security. It could as serve a test bed for creating integrated Activity-Based Simulation models -- hybrid activity-based models (service models) for discrete and continuous simulations that execute independently -- for distributed enterprises and also for integrating mobile agents without introducing complexities into the SOS. Using AXIOM 2 and Design for Six Sigma (DFSS) scientific concepts, the generic model could serve as a template for predicting in advance the performance of ***edge*** enterprises under the constraints defined by the enterprises.

QUESTIONS???