NDIA
SYSTEM
ENGINEERING
CONFERENCE

JOG SYSTEM ENGINEERING
GRAND SYSTEMS DEVELOPMENT TRAINING PROGRAM
PRESENTATION

A SIMPLE PRESCRIPTION FOR REQUIREMENTS SUCCESS

Who Is Jeff Grady?

CURRENT POSITION

President, JOG System Engineering
System Engineering Consulting and Education Firm

PRIOR EXPERIENCE

U.S. Marines

General Precision, Librascope Division

- Customer Training Instructor, SUBROC and ASROC ASW Systems

Ryan Aeronautical Company (later Teledyne Ryan Aeronautical)

- Field Engineer, AQM-34 Series Special Purpose Aircraft
- Project Engineer, System Engineer, Unmanned Aircraft Systems

General Dynamics, Convair Division

- System Engineer, Cruise Missile, Advanced Cruise Missile

General Dynamics Space Systems Division

- Functional Engineering Manager, Systems Development Department

FORMAL EDUCATION

SDSU, BA Math; UCSD, Systems Engineering Certificate;
USC, MS Systems Management with Information Systems Certificate

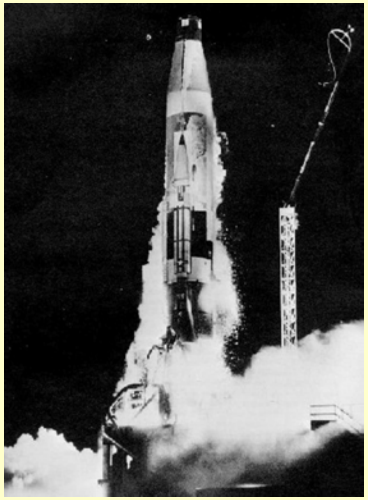
INCOSE First Elected Secretary, Founder, Fellow, ESEP

AUTHOR System Requirements Analysis (2), System Integration, System Validation and Verification, System Engineering Planning and Enterprise Identity, System Engineering Deployment, System Verification, System Synthesis, System Management

Systems Jeff Grady Worked On

USN/Librascope
ASROC/SUBROC
Computer Systems

USAF/GD Convair AQM 129
Advanced Cruise Missile



USAF/GD Atlas Missile

USAF/Ryan AQM-81 Firebolt

Ryan Aeronautical War Birds

USAF/Ryan Models 147G, NX, H, and J at Bien Hoa, SVN

USAF/Ryan AQM-34L Tom Cat
58 Combat Missions

U.S. Navy/Ryan
Model 147SK

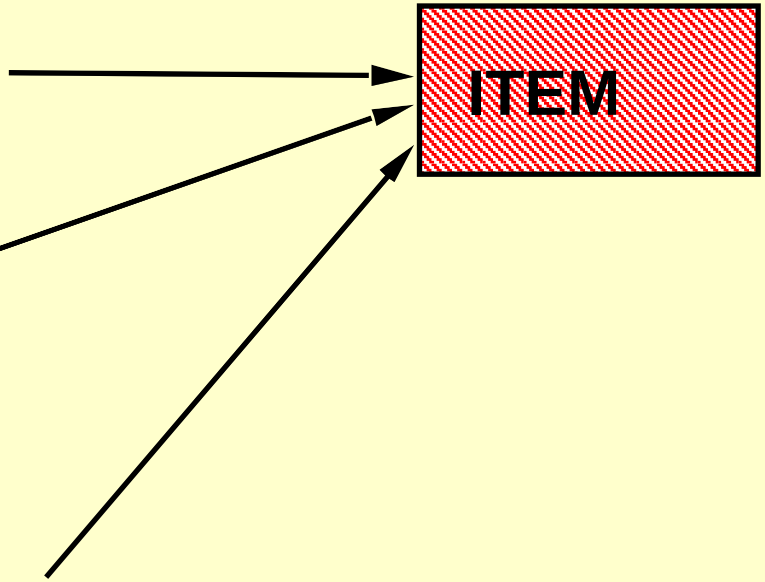
USAF/Ryan
BGM-34C

The Prescription Plan

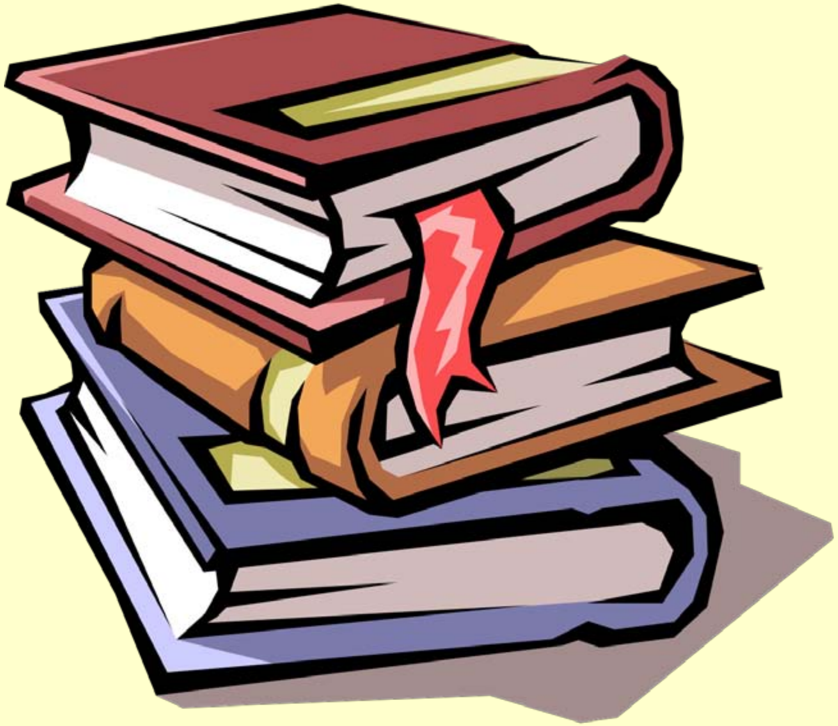
- Introduce ideas to be applied
- Program preparation steps
  - Preparation process overview
  - Specification templates
  - Organizational structure and responsibilities
  - Modeling preferences and modeling work product capture
  - Specification map
- Program implementation steps
- Modeling overview
- Traditional Structured Analysis as a Universal Architecture Description Framework (UADF)
  - RAS-Complete to collect the modeling results
  - MSA and PSARE teamed up as a UADF
  - UML teamed up with SysML as a UADF
- Specification publishing and a look into the future

Requirement Defined

- Something wanted or necessary.
- Something essential to the existence or occurrence of something else.
- A necessary characteristic or attribute of some thing, entity, or item.



What is a Specification?



A specification contains all of the requirements for a given item.

A Current Reality

- Many system engineers and managers have the opinion that their organization does not perform requirements analysis and specification publishing well.
- Unfortunately, many of these engineers and managers are right about their organization's performance in this area.
- There seems to be a void of knowledge among these engineers and managers about how to avoid this problem, about how to bring about an improvement in the performance of their organization.

Some Elementary Logic

- If what you are now doing is not working well, it stands to reason that if you keep doing what you are doing then the outcome will continue to be unsatisfactory (a variation on the definition of insanity to expect otherwise)
- You may have to undergo a change in how you accomplish this work.
- The purpose of this presentation is to offer one effective route to correcting the problem.
- There may be other ways to fix the problem as well but this one will work.

The Top-Level Program Structure

- The development organization should follow a pattern of first defining the requirements in a set of performance specifications, one for each entity in the system. These system and item specifications must also include the system test and evaluation and item qualification verification requirements respectively.
- Step two is to accomplish synthesis in a trio of transformations: (1) requirements to design solutions, (2) design solutions to material acquisition, and (3) available materials to manufactured product.
- When the design for an item is essentially complete, develop a detail specification for use as the basis for item product acceptance verification subsequent to manufacture.

The Top-Level Program Structure

- The third program step is to verify that the manufactured product satisfies the requirements in the specifications that should have driven the design.
  - System Specification content drives system development test and evaluation plans and procedures.
  - Item Performance Specification content drives item qualification verification plans and procedures.
  - Item Detail Specification content drives item acceptance test plans and procedures accomplished on every production article.
- Accomplish the three fundamental steps within a sound management infrastructure

The System Development Sequence In Summary

- **Define the problem**
  - Specifications
- **Solve the problem**
  - Design, procurement/material, and manufacturing
- **Prove it**
  - Verification
- **All within a sound technical management infrastructure**

The Prescription - Preparatory Steps

1. Establish a written criteria of acceptability for all specifications created.
2. Select a set of specification templates including one for every kind of specification the enterprise will ever have to prepare on a program.
3. Base requirements definition on the use of models.
4. Select a set of models that form a universal architecture description framework (UADF) that is comprehensive relative to system, hardware, and software entities.
5. Coordinate the specification template paragraph structures with responsible functional departments and analytical models that will be applied in identifying specification content.

The Prescription - Preparatory Steps

6. Coordinate the specification template paragraphing structure with the models used such that all of the requirements derived from one model fall into one portion of the specification paragraphing structure.
7. Craft a template for a structured analysis modeling work product capture document within which a program structured analysis model base can be configuration managed – System Architecture Report (SAR).
8. Train personnel in the application of assigned models such that they arrive on a program ready to accomplish assigned work. A common process on all programs can be a part of this by encouraging process repetition.

The Prescription - Implementation Steps

1. Where multiple modeling sets are employed in an enterprise, determine models that will be applied on the particular program for system, hardware, and software entities. Work toward a common set (a UADF).

2. Select templates for system, hardware, and software entity specifications.

3. Build a specialty engineering scoping matrix for the program and coordinate discipline expectations with team budget limitations.

4. Form a PIT that will accomplish system level structured analysis using selected models identifying the content of the system specification and specifications corresponding to the top level IPPT.

The Prescription - Implementation Steps

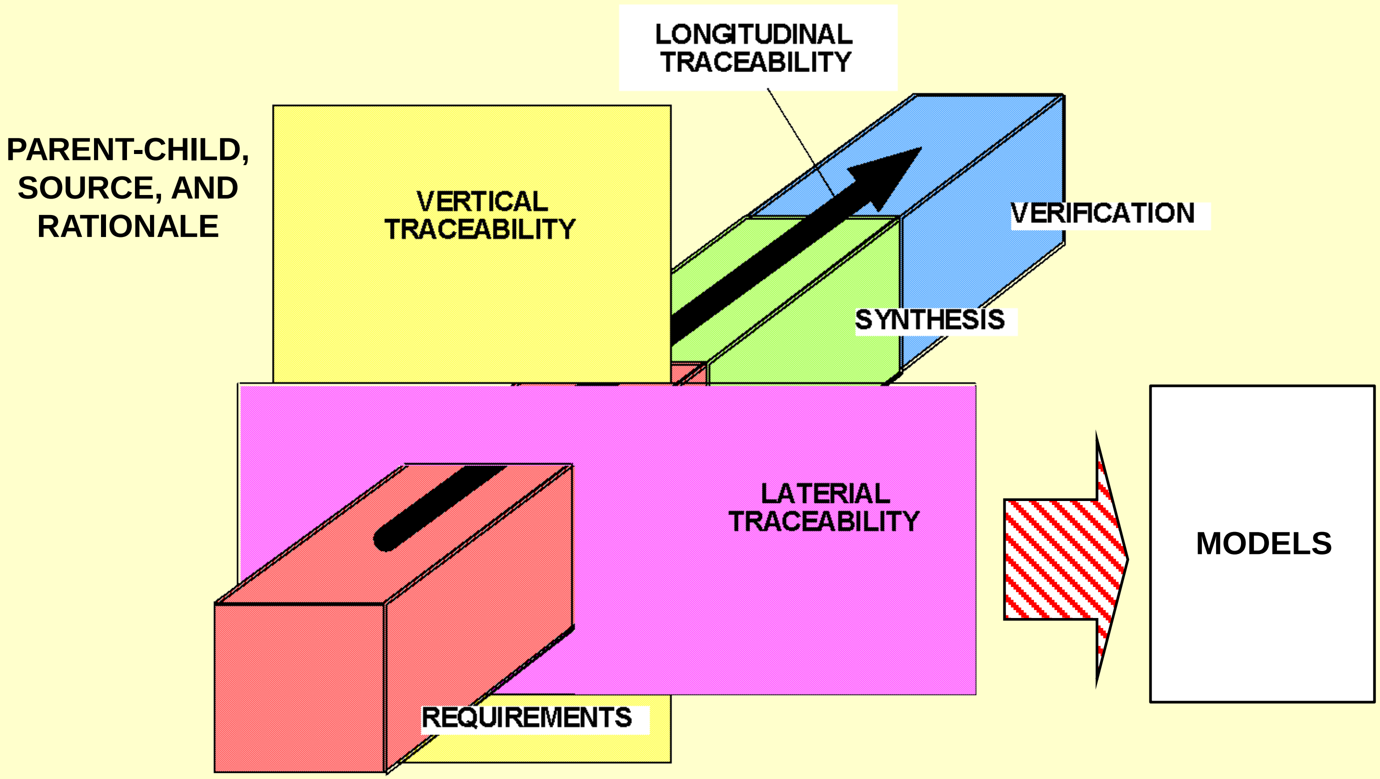
5. Apply functional models to determine what the system and entities must do and how well they must do it. Coordinate performance requirements analysis with product entity and interface needs.
6. Apply models for interface, specialty engineering, and environmental requirements analysis.
7. Each IPPT should come aboard with a specification and program planning complete for the entity for which they will be responsible.
8. IPPT continue lower tier structured analysis with appropriate models.
9. Employ a program-wide RAS-Complete in a computer database to capture the requirements flowing from all of the models used.

The Prescription - Implementation Steps

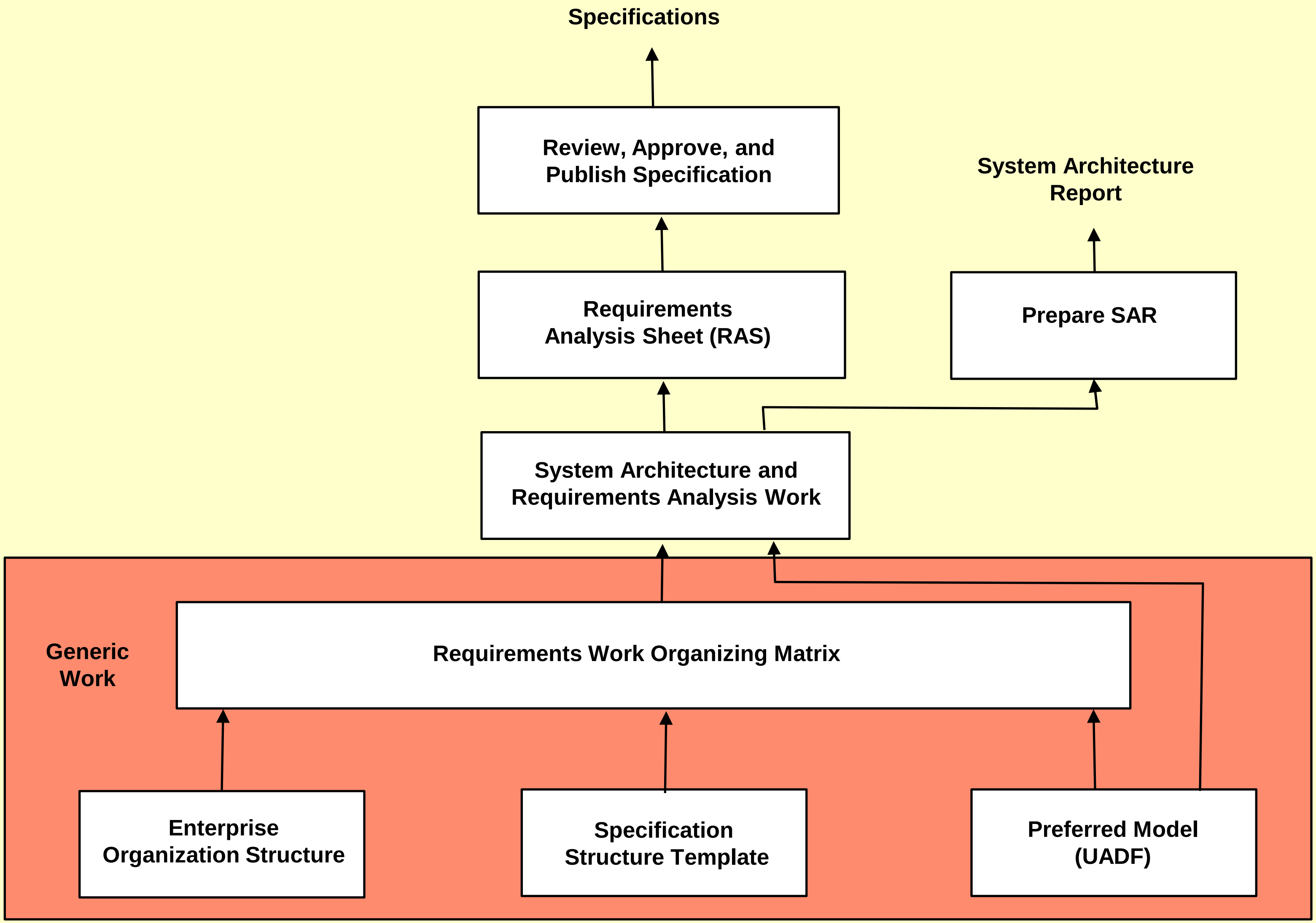
10. Employ a computer application that sets the RAS database filter to a particular product entity and part (performance or detail) and orders the database content by paragraph number so as to print a specification to screen or paper.
11. Apply sound risk management techniques and formally review all specification and changes for release.
12. Configuration manage released specifications and changes.
13. Require that every new specification and every change to a previously approved specification be reviewed and approved in response to a written criteria for acceptability.
14. Use the verification requirements in the system and item performance specifications as the basis for system DT&E and item qualification verification plans and procedures.

The Prescription - Implementation Steps

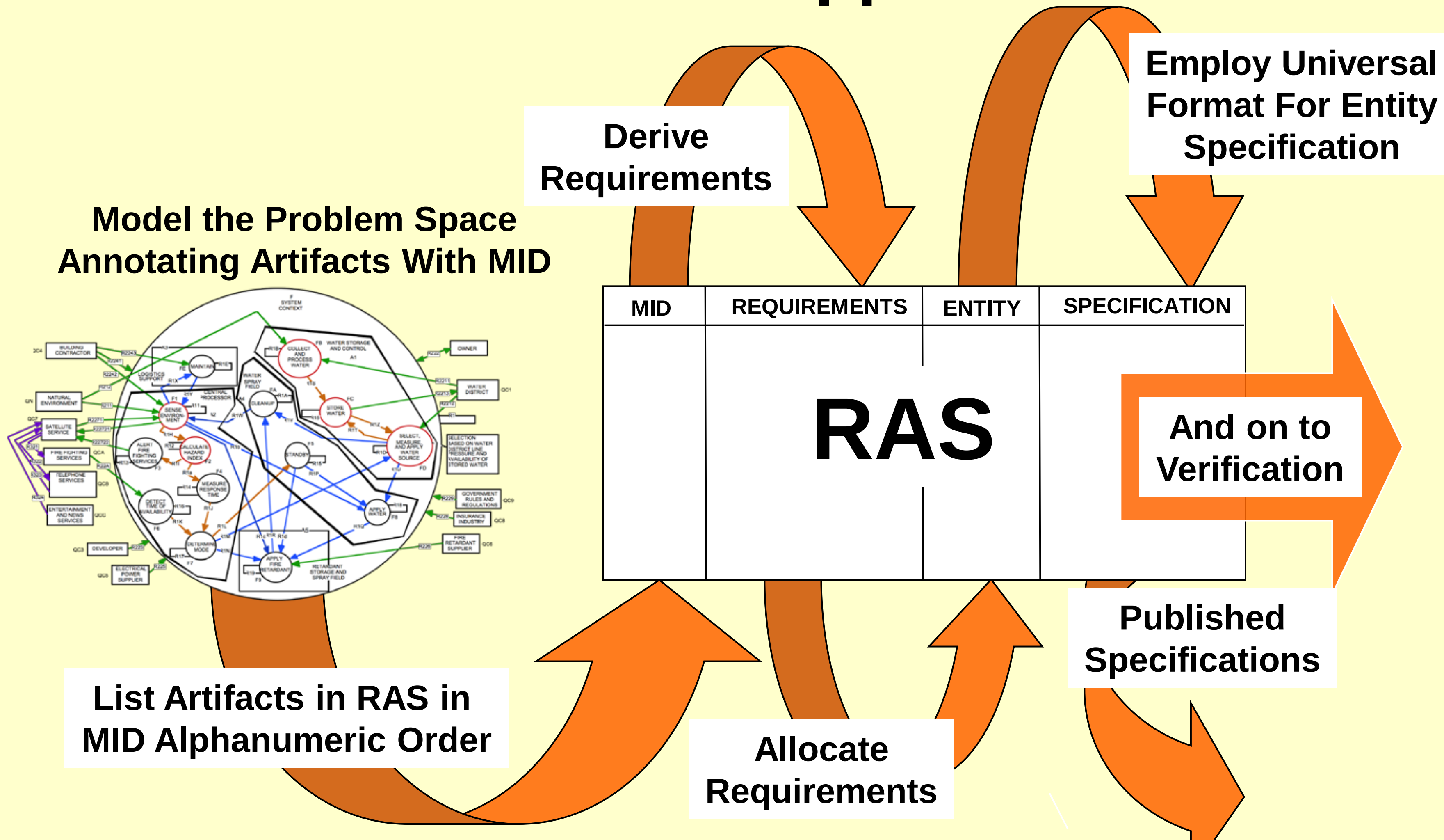
15. Maintain three-dimensional traceability (vertical, longitudinal, and lateral) to the extent possible.



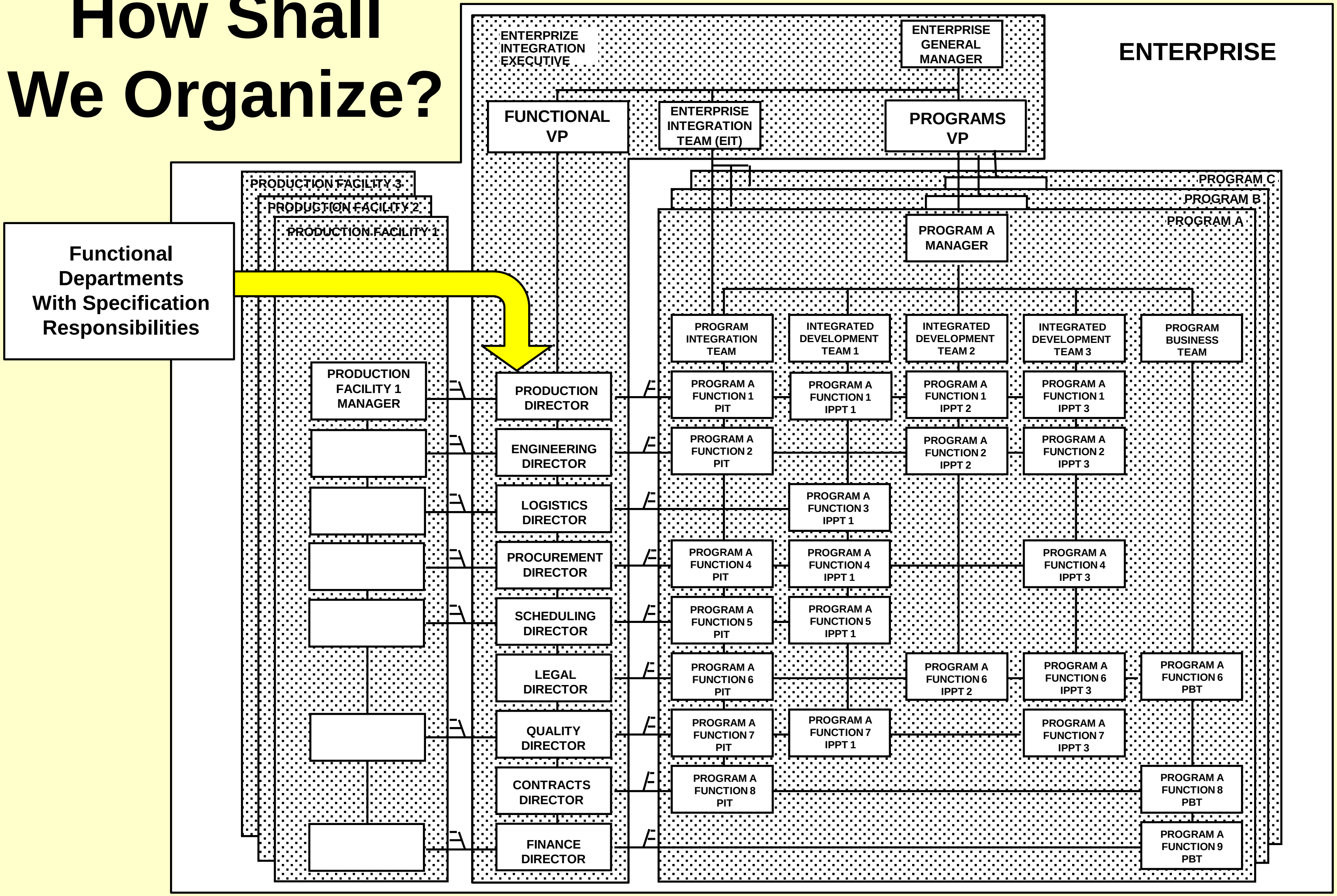
The Prescription in a Picture



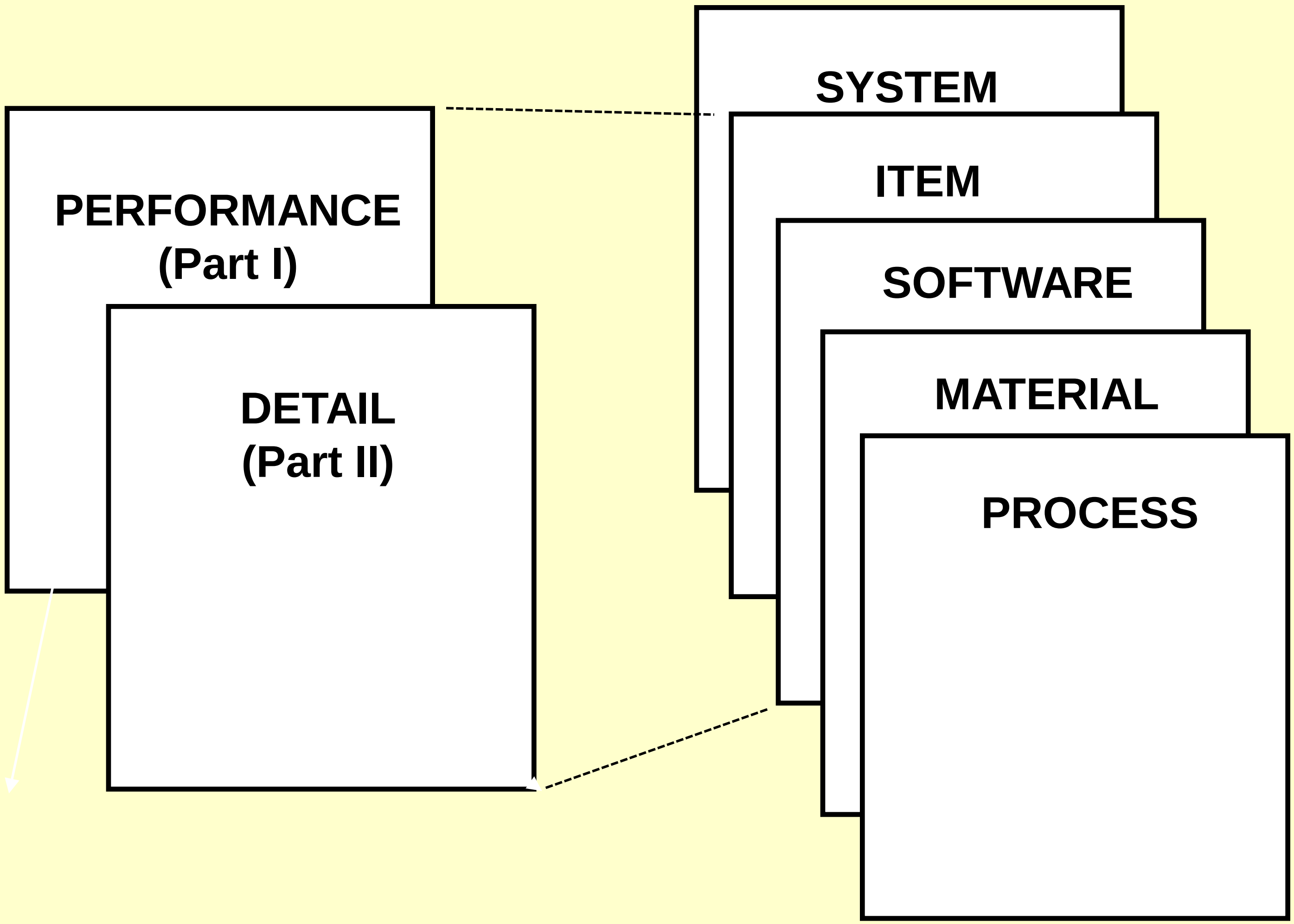
Universal Architecture Description Framework Approach



How Shall We Organize?

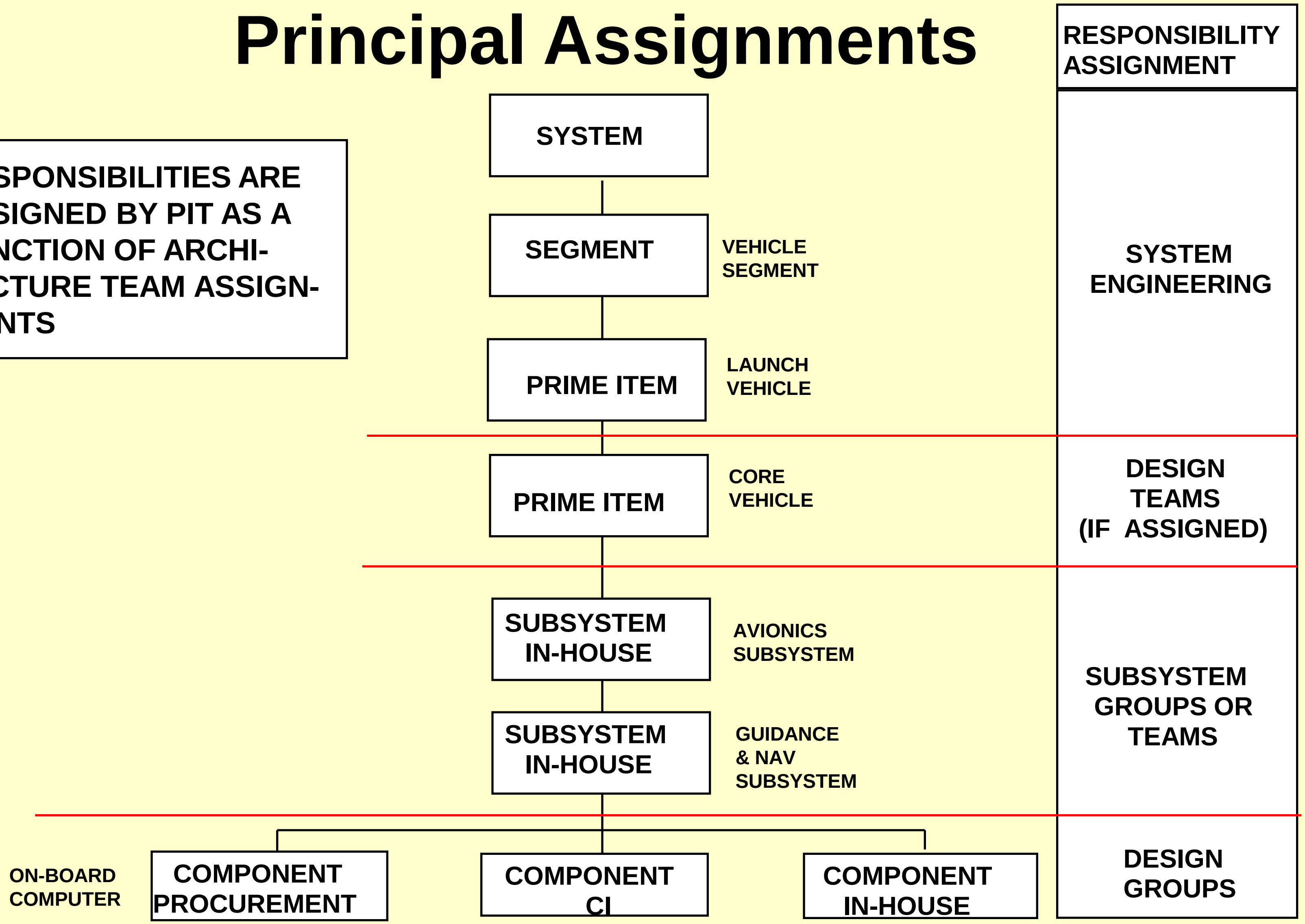


MIL-STD-961E Specification Types

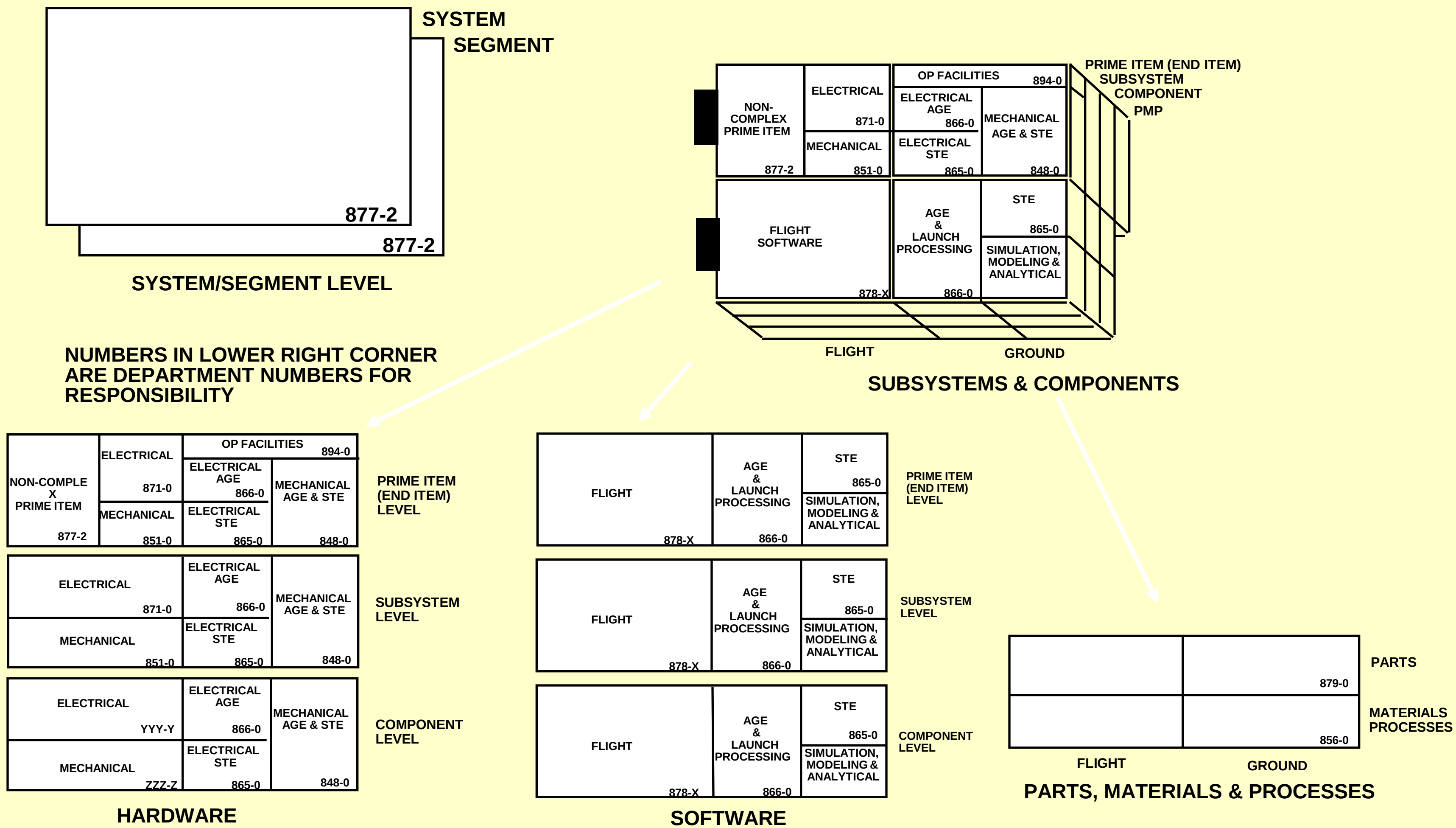


Requirements Documentation Principal Assignments

RESPONSIBILITIES ARE ASSIGNED BY PIT AS A FUNCTION OF ARCHITECTURE TEAM ASSIGNMENTS



Requirements Documentation Responsi-bilities by Element Type and Level



A Template

Using the Six-Section Military Format as a Basis

1. Scope
2. Applicable Documents
3. Requirements
4. Verification
5. Packaging
6. Notes

Specification Template, Model Preference, and Responsibility Map

PARAGRAPH NUMBER	TITLE	RESPONSIBLE DEPARTMENT	PREFERRED MODEL	SAR APP
1	SCOPE			
2	APPLICALE DOCUMENTS			
3	REQUIREMENTS	D216-2	-	
3.1	Requirements Driven Sources	D216-2	-	
3.1.1	Non-Modeling Sources	D216-2	-	
3.1.1.1	Customer Need	D216-2	-	
3.1.1.2	Missions	D216-2	Mission Analysis	A
3.1.1.3	Threat	D216-2	Threat Analysis	B
3.1.1.4	Ad hoc Sources	D216-2	-	
3.1.2	Problem Space Modeling	D216-2	-	
3.1.2.1	Functional Flow Diagramming	D216-2	Functional Analysis	A
3.1.2.2	Functional Dictionary	D216-2	Functional Analysis	A
3.1.2.3	Requirements Analysis Sheet	D216-2	Functional Analysis	G
3.1.3	Solution Space Modeling	D216-2	Constraints Analysis	
3.1.3.1	Product Entity Modeling	D216-2	Product Entity Block Diagramming	C
3.1.3.2	Interface Modeling	D216-2	Schematic Block Diagramming	D
3.1.3.3	Specialty Engineering Modeling	D216-2		E
3.1.3.4	Environmental Spaces and Modeling	D216-2	Environmental Modeling	B
3.2	System Capabilities	D216-2	Functional Analysis	A
3.2.m	Capability m	D216-2	Functional Analysis	A
3.2.m.n	Performance Requirement n	D216-2	Performance Requirements Analysis	

Specification Template, Model Preference, and Responsibility Map

PARAGRAPH NUMBER	TITLE	RESPONSIBLE DEPARTMENT	PREFERRED MODEL	SAR APP
3.3	Interface Requirements	D216-2	Interface Requirements Analysis	D
3.3.1	Crossface Requirements	D216-2	Schematic Block Diagram	D
3.3.2	Innerface Requirements	D216-2	Schematic Block Diagram	D
3.3.3	Outerface Requirements	D216-2	Schematic Block Diagram	D
3.3.4	Government-Furnished Property (GFP) Interfaces	D216-2	N-Square Analysis	D
3.4	Specialty Engineering Requirements	D216-2	Specialty Engineering Modeling	E
3.4.1	Reliability	D216-4	Reliability Modeling	E
3.4.2	Maintainability	D216-4	Maintainability Modeling	E
3.4.3	Availability	D216-4	RAM Modeling	E
3.4.4	Deployability and Transportability	D231 D231	Logistics Analysis	E
3.4.5	Logistics	D231	Logistics Analysis	E
3.4.5.1	Maintenance	D216-4	Logistics Analysis	E
3.4.5.2	Interchangeability	D231	Logistics Analysis	
3.4.5.3	Supply	D231	Logistics Analysis	E
3.4.5.4	Facilities and Facility Equipment	D231	Logistics Analysis	E
3.4.5.5	Personnel	D231	Logistics Analysis	E
3.4.5.6	Training	D231	Logistics Analysis	E
3.4.6	Safety	D216-5	Safety Hazard Analysis.	E
3.4.7	Human Factors Engineering	D216-5	Human Engineering Analysis	E

Specification Template, Model Preference, and Responsibility Map

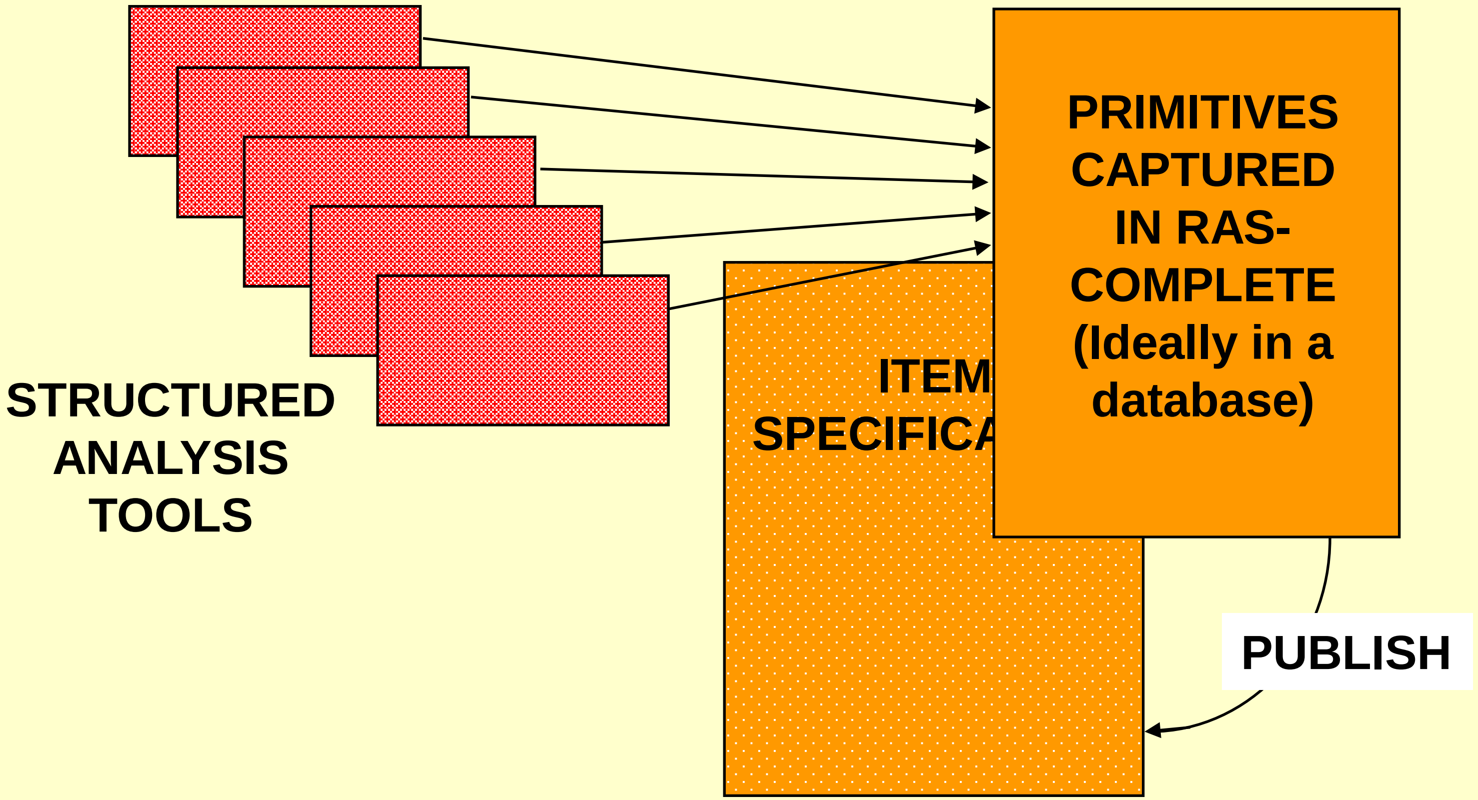
PARAGRAPH NUMBER	TITLE	RESPONSIBLE DEPARTMENT	PREFERRED MODEL	SAR APP
3.4.8	Security and Privacy	D216-6	System Security Analysis	E
3.4.9	Electromagnetic Radiation	D213-3	Electromagnetic Analysis	E
3.4.10	Lightning Protection			E
3.4.11	Producibility	D224	Manufacturing Require- ments Analysis	E
3.4.12	Affordability			E
3.4.13	Computer Resource Requirements	D213-2		E
3.4.14	Design and Construction	D211-3	Configuration Management	E
3.4.14.1	Quality Enginering			E
3.4.14.2	Parts, Materials, and Processes	D216-7	Parts, Materials and Processes Analysis	E
3.4.14.3	Workmanship			E
3.4.14.4	Nameplates and Product Markings	D211-3	Configuration Manage- ment Techniques	E
3.4.14.5	Serialization			E
3.4.14.6	Mass Properties			E
3.4.14.7	Structural Properties			E
3.4.14.8	Shock and Vibration			E
3.4.14.9	Earthquake Survivability			E
3.4.14.10	Aerodynamics			E
3.4.14.11	Thermodynamics			E
3.4.14.12	Chemical, Electrical, and Mechanical Properties			E
3.4.14.13	Stability			E
3.4.14.14	Coatings			E

Specification Template, Model Preference, and Responsibility Map

PARAGRAPH NUMBER	TITLE	RESPONSIBLE DEPARTMENT	PREFERRED MODEL	SAR APP
3.5	Environmental Requirements	D216-2	Environmental Requirements Analysis	B
3.5.1	Natural Environmental Requirements	D216-2	Standards Analysis	B
3.5.2	Hostile Environmental Requirements	D216-2	Threat Analysis	B
3.5.3	Non-Cooperative Environmental Requirements	D216-2		B
3.5.4	Self-Induced Environmental Requirements	D216-2		B
3.5.5	Environmental Impact Limitations	D216-2		B
3.6	Precedence and Criticality of Requirements	D216-2		E
4	VERIFICATION			
5	PACKAGING			
6	NOTES			

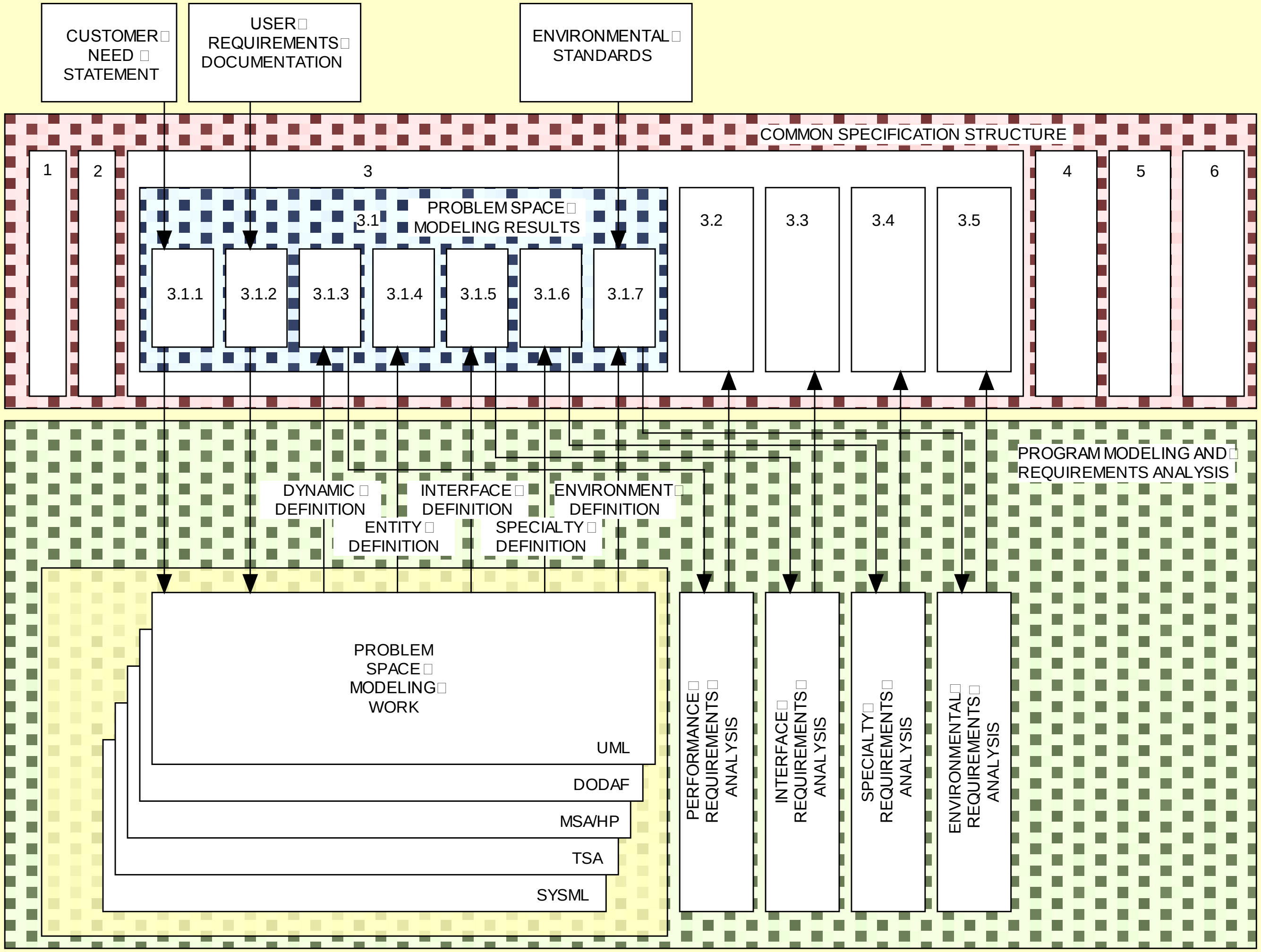
Lateral Traceability

Models as Characteristic List Builders



Building Universal Specifications

With Perfect Modeling Alignment



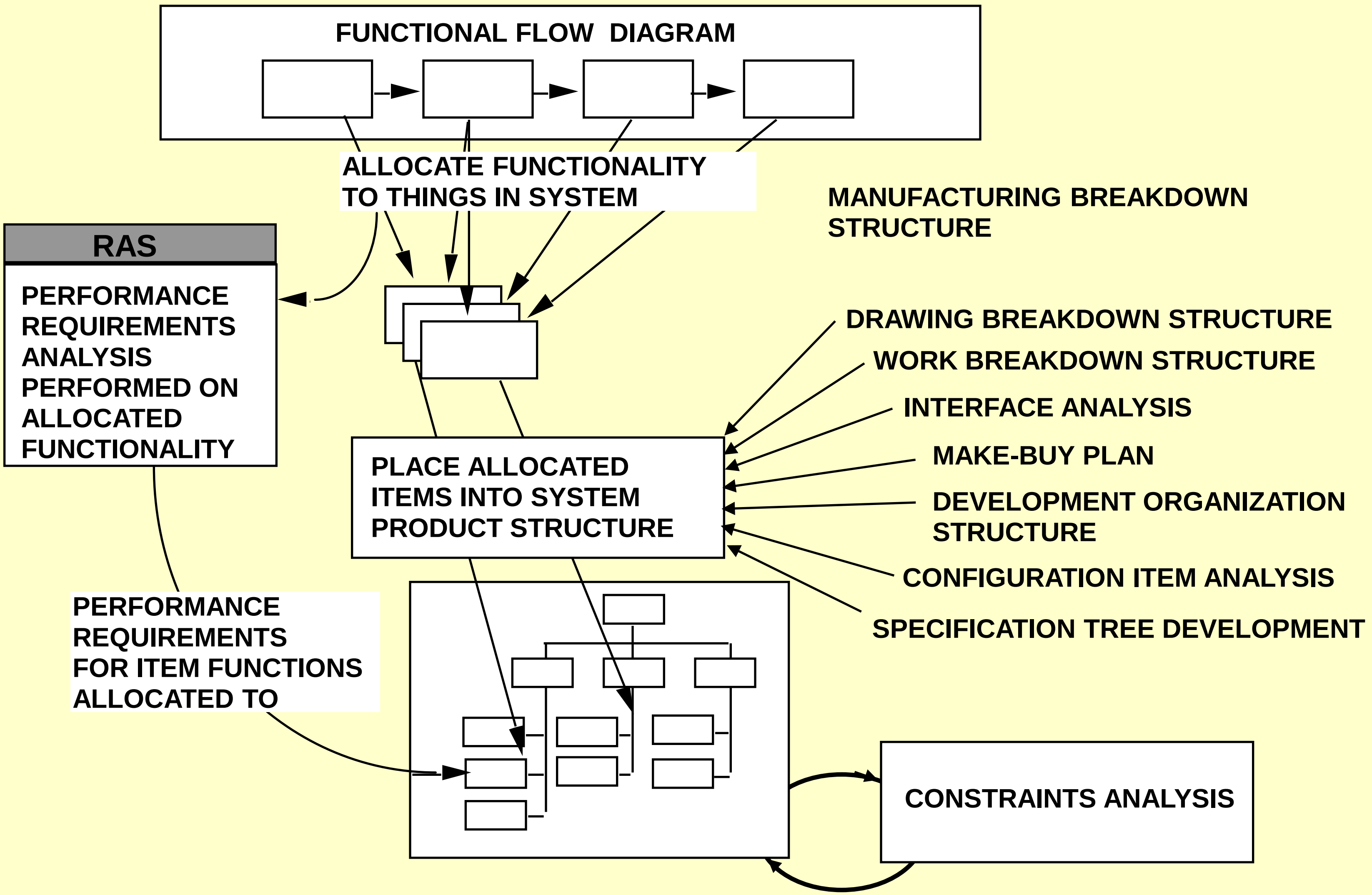
Three Ways to Capture the Modeling

- Within specification paragraph 3.1.3 on a program with few specifications
- In a system architecture report (SAR) referenced in paragraph 3.1.3
- Within the computer tool used to accomplish the modeling work with a reference in paragraph 3.1.3 to the tool content

Overview of Available Comprehensive Models

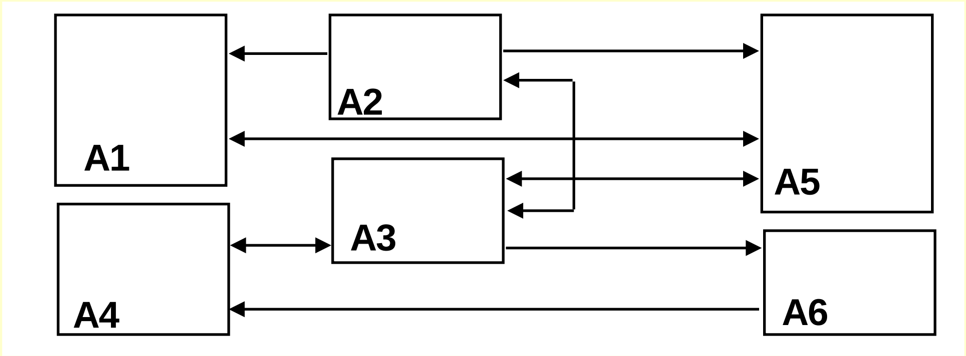
- Traditional Structured Analysis UADF
  - Functional modeling
  - Product entity and interface modeling
  - Specialty engineering modeling
  - Environmental modeling
- MSA/PSARE UADF
- UML/SysML UADF

TSA Function Allocation



TSA Interface Definition Models

SCHEMATIC BLOCK DIAGRAMMING



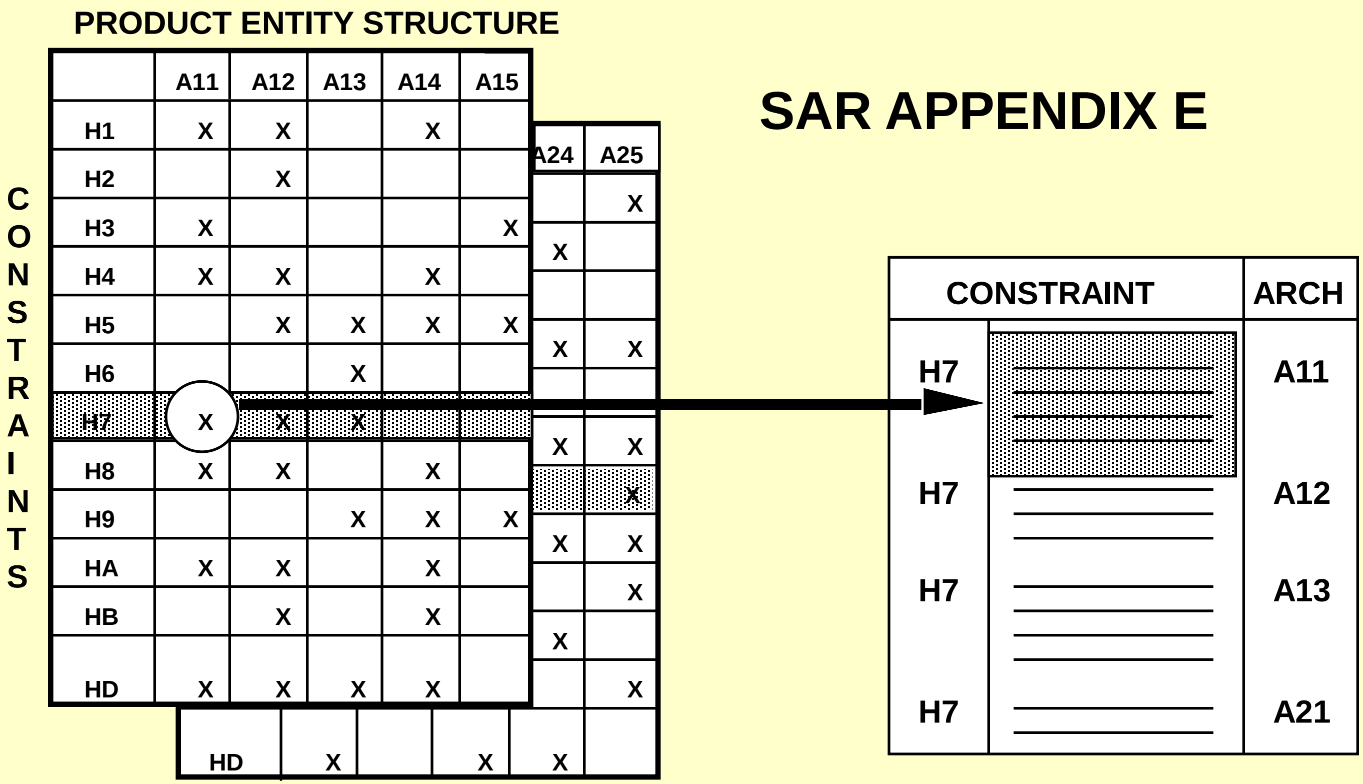
- Lines define interfaces
- Blocks are objects only from the product entity structure diagram

N-SQUARE DIAGRAMMING

A1				X	
X	A2	X		X	
	X	A3	X	X	X
		X	A4		
X		X		A5	
			X		A6

- Marked intersections define interfaces
- Diagonal blocks are objects only from product entity block diagram
- Apparent ambiguity reflects directionality

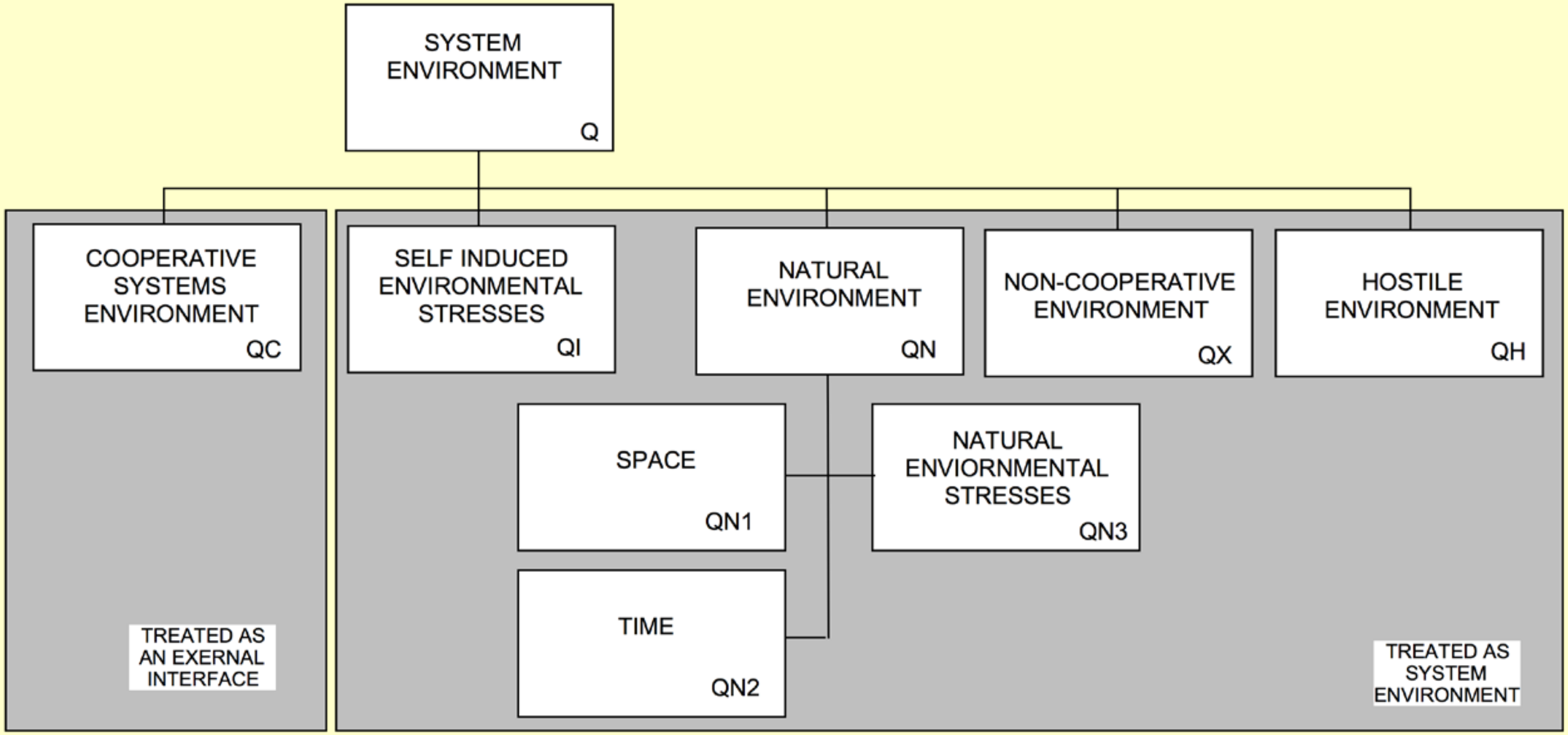
TSA Specialty Engineering Identification of Requirements



PRODUCT ENTITY-SPECIALTY ENGINEERING MATRIX
(DESIGN CONSTRAINTS SCOPING MATRIX)

SPECIALTY ENGINEERING REQUIREMENTS FLOW INTO THE INDICATED SPECIFICATIONS THROUGH THE RAS

TSA Environment Subsets



Some would add a software subset

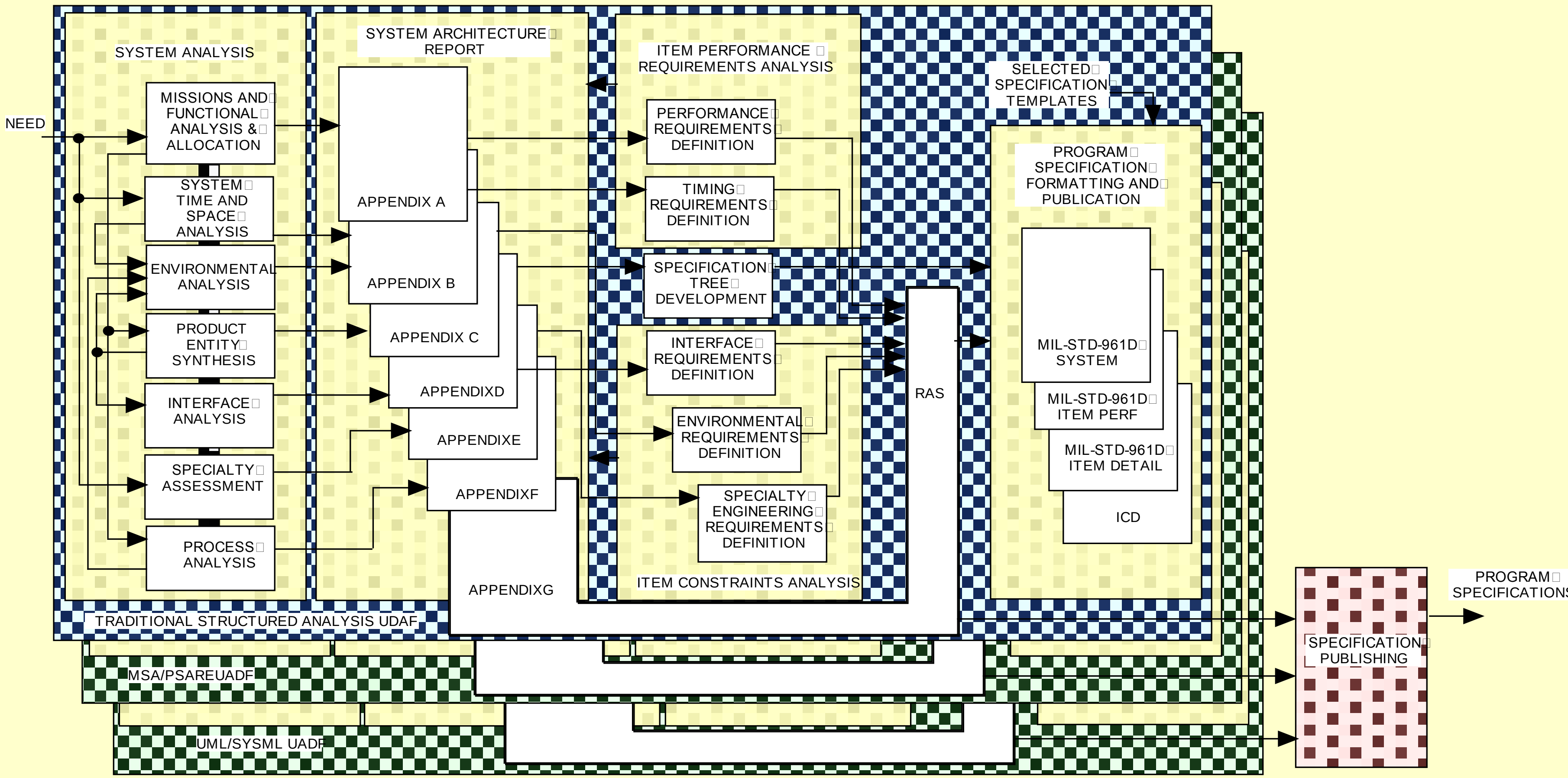
Environmental Requirements Model

- **System**
  - Identify spaces within which the system will have to function
  - Select standards covering those spaces
  - For each standard, select parameters that apply
  - Tailor the range of selected parameters
- **End item**
  - Build three dimensional model of end items, physical processes, and process environments
  - Extract item environments
- **Component**
  - Zone end item into spaces of common environmental characteristics
  - Map components to zones
  - Components inherit zone environmental requirements

RAS – Complete
Using TSA UADF

MODEL ENTITY		REQUIREMENT ENTITY		PRODUCT ENTITY		DOCUMENT ENTITY	
MID	MODEL ENTITY NAME	RID	REQUIREMENT	PID	ITEM NAME	PARA	TITLE
F47	Use System			A	Product System		
F471	Deployment Ship Operations			A	Product System		
F4711	Store Array Operationally	XR67	Storage Volume < 10 ISO Vans	A1	Sensor Subsystem		
H	Specialty Engineering Disciplines			A	Product System		
H11	Reliability	EW34	Failure Rate < 10 x 10-6	A1	Sensor Subsystem	3.1.5	Reliability
H11	Reliability	RG31	Failure Rate < 3 x 10-6	A11	Cable	3.1.5	Reliability
H11	Reliability	FYH4	Failure Rate < 5 x 10-6	A12	Sensor Element	3.1.5	Reliability
H11	Reliability	G8R4	Failure Rate < 2 x 10-6	A13	Pressure Vessel	3.1.5	Reliability
H12	Maintainability	6GHU	Mean Time to Repair < 0.2 Hours	A1	Sensor Subsystem	3.1.6	Maintainability
H12	Maintainability	U9R4	Mean Time to Repair < 0.4 Hours	A11	Cable	3.1.6	Maintainability
H12	Maintainability	J897	Mean Time to Repair < 0.2 Hours	A12	Sensor Element	3.1.6	Maintainability
H12	Maintainability	9D7H	Mean Time to Repair < 0.1 Hours	A13	Pressure Vessel	3.1.6	Maintainability
I	System Interface			A	Product System		
I1	Internal Interface			A	Product System		
I11	Sensor Subsystem Innerface			A1			
I181	Aggregate Signal Feed Source Impedance	E37H	Aggregate Signal Feed Source Impedance= 52 ohms ± 2 ohms	A1	Sensor Subsystem		
I181	Aggregate Signal Feed Load Impedance	E37I	Aggregate Signal Feed Load Impedance= 52 ohms ± 2 ohms	A4	Analysis and Reporting Subsystem		
I2	System External Interface			A	Product System		
Q	System Environment			A	Product System		
QH	Hostile Environment			A	Product System		
QI	Self-Induced Environmental Stresses			A	Product System		
QN	Natural Environment			A	Product System		
QN1	Temperature	6D74	-40 degrees F< Temperature < +140 degrees F	A	Product System		
QX	Non-Cooperative Environmental Stresses			A	Product System		

Lateral Traceability
Through the RAS and SAR

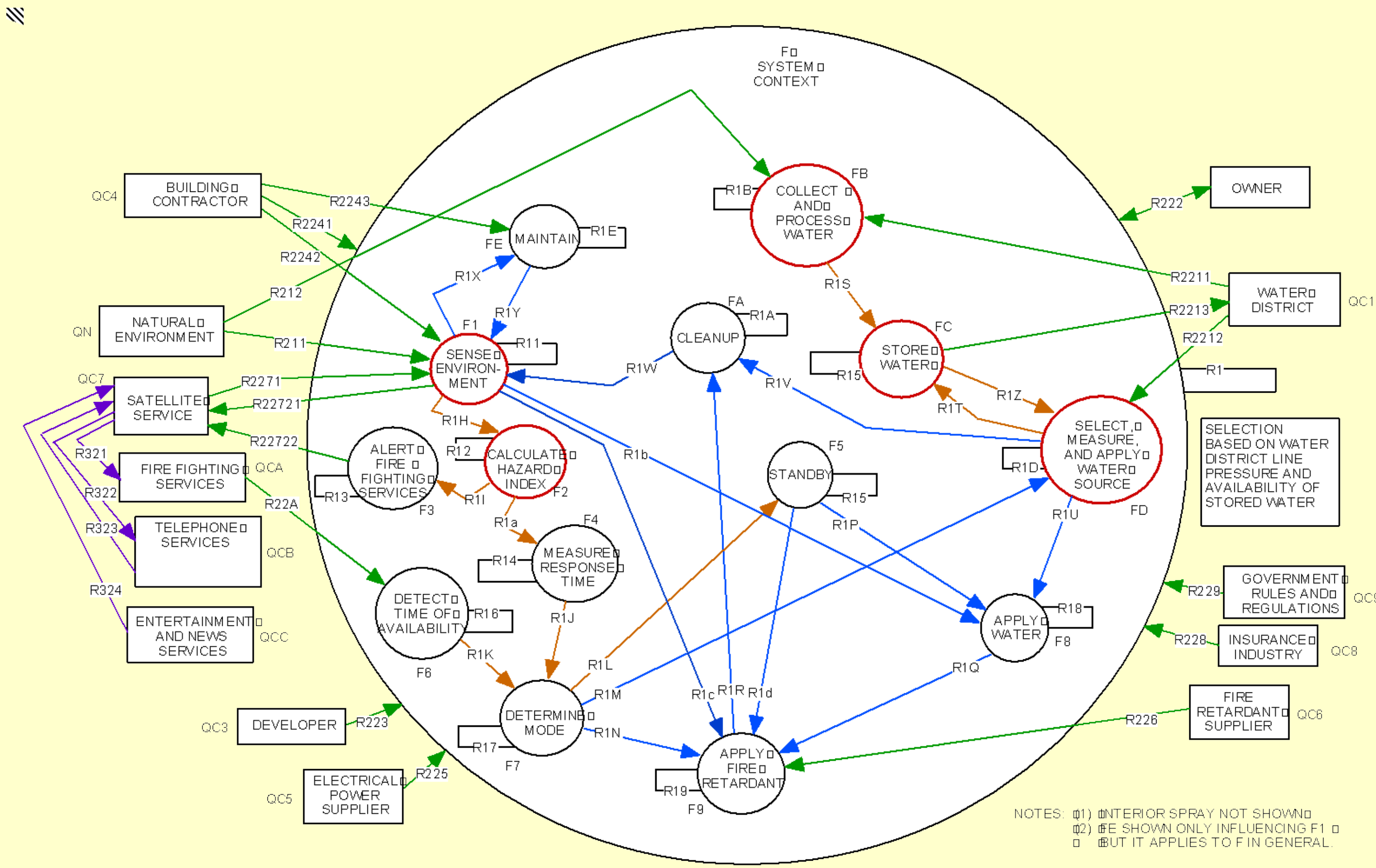


MSA/PSARE as a UADF

- PSARE provides a complete UDAF problem space model
- Alternatives for the solution space model
  - Simply use the PSARE architecture model but some parts still not covered so augment with environmental modeling and specialty engineering modeling
  - Replace the PSARE architecture model with the common solution space model set
    - » Product entity structure identified by super bubbles
    - » Specialty engineering scoping matrix and specialty models
    - » Three-layered environmental model
    - » Interfaces handled by "data flow"
    - » RAS

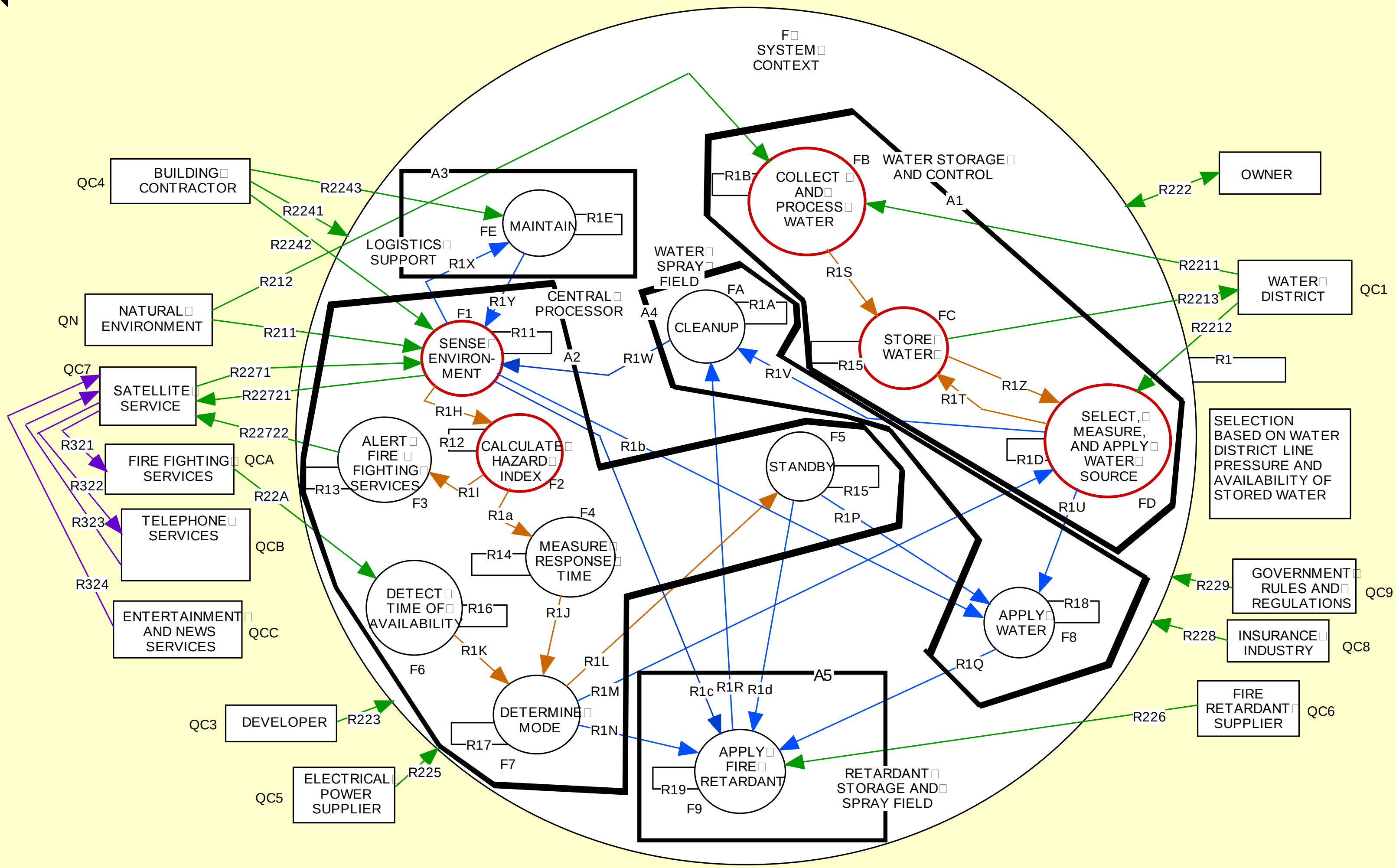
MSA/PSARE

Sample System Analysis – Context Diagram Expansion

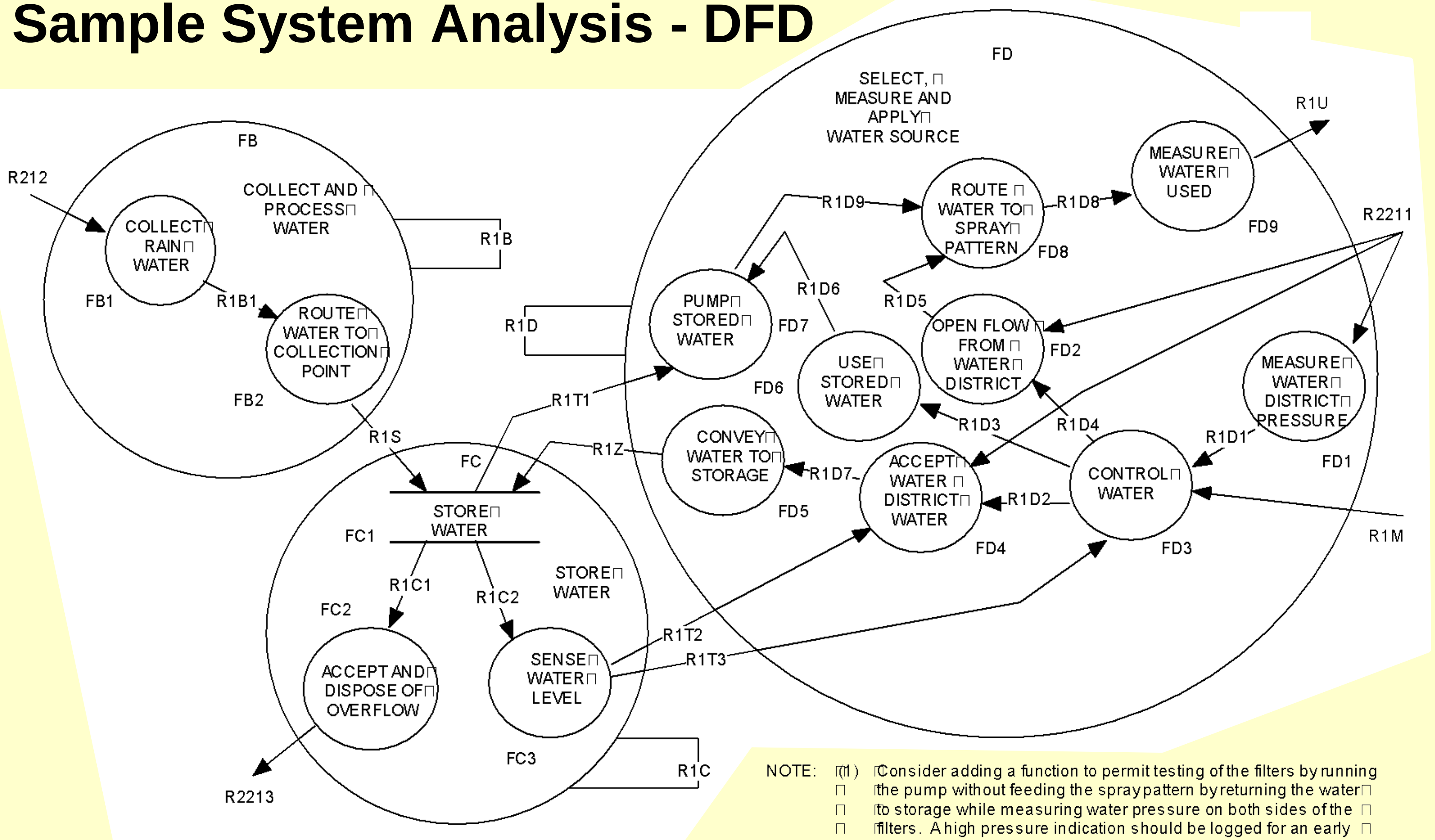


MSA/PSARE

Sample System Analysis - Super Bubbles



PSARE
Sample System Analysis - DFD



NOTE:
(1) Consider adding a function to permit testing of the filters by running the pump without feeding the spray pattern by returning the water to storage while measuring water pressure on both sides of the filters. A high pressure indication should be logged for an early maintenance response.
(2) Consider adding a function and relationship that directs the water flow from function FD8 onto the facility from the direction of the fire rather than from all directions.
(3) Water used must be measured before the spray pattern rather than after.

P-Spec Sample

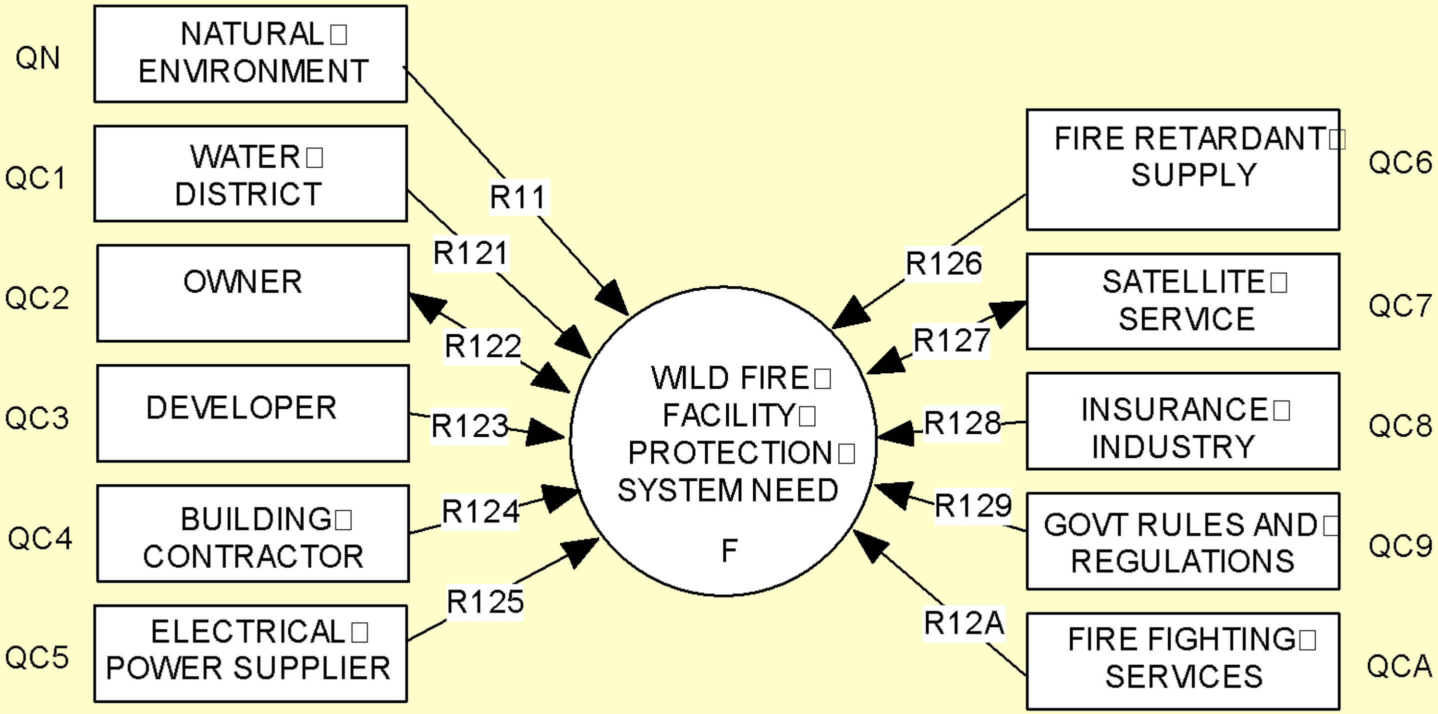
MID	FC1	
TITLE	STORE WATER	
PERSECTIVE	MATERIAL STORAGE	
FIGURE	C-1 SHEET 3	
INFLOWS	R18	local rainwater collected. This water should be filtered in some fashion at least to the extent that silt does not accumulate in the storage vessel.
	R1Z	Water District water made available to increase stored water.
OUTFLOWS	R1T1	Water from storage for use in the facility water deluge. Some form of filtering is necessary to prelude debris jamming of the pump being fed. Related plumbing must be able to handle a100 gallons per minute pump rate.
TRANSFORMATION	1.	Output equals input except that if the vessel is open to the environment some stored water will be lost due to evaporation.
	2.	It is necessary for the storage vessel to have a capacity of TBD-1 gallons.
	3.	The storage vessel may be a tank of metal or fiberglass construction above ground or buried, a swimming pool, or a naturally appearing pond or one fashioned in the ground through an earth moving operation. A tower tank is not encouraged because of the owner requirement in paragraph 3.1.2.1.2 regarding appearance.

A Data Dictionary Fragment

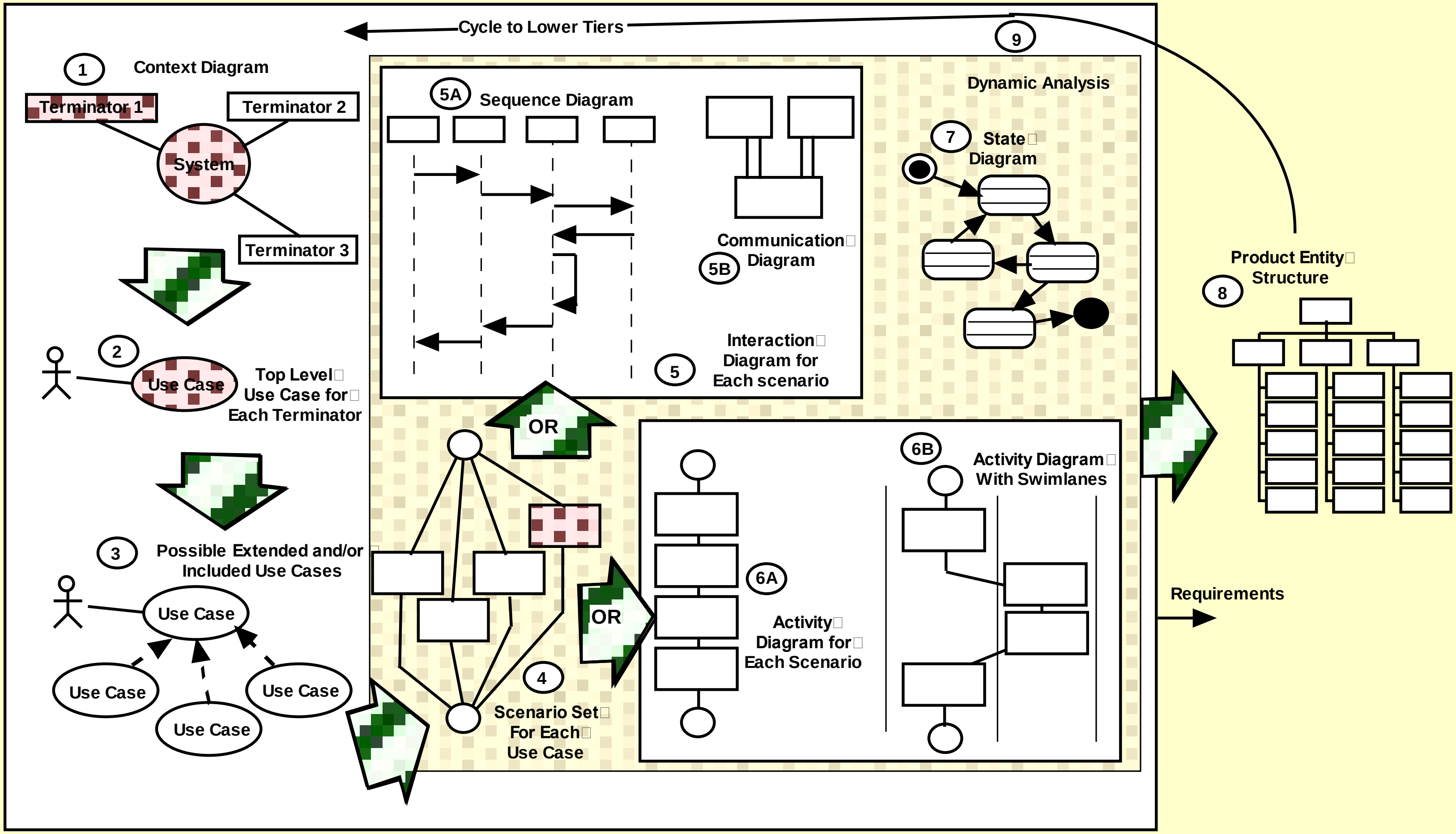
Table C-1 Data Dictionary (Continued)

MID SYMBOL	NAME	SOURCE	DESTINATION	DESCRIPTION
R1L	F7-F5 Relationship	F7	F5	Command entry into Standby Mode.
R1M	F7-FD Relationship	F7	FD	Command Water Deluge Mode.
R1N	F7-F9 Relationship	F7	F9	Command Retardant Deluge Mode.
R1P	F5-F8 Relationship	F5	F8	Command Water Deluge Mode.
R1Q	F8-F9 Relationship	F8	F9	Command Retardant Deluge Mode.
R1R	F9-FA Relationship	F9	FA	
R1S	FB-FC Relationship	FB	FC	Rain water flows from the collection network to the storage medium,
R1T	FC-FD Relationship	FC	FD	
R1T1	Stored Water to Pump	FC1	FD7	Stored water flows to the pump intake.
R1T2	Stored Water Level Low	FC3	FD4	Stored water sufficiently low to demand replenishment from water district source.
R1T3	Stored Water Level Adequate	FC3	FD3	Stored adequate to support water deluge.
R1U	FD-F8 Relationship	FD	F8	
R1V	FD-FA Relationship	FD	FA	
R1W	FA-F1 Relationship	FA	F1	
R1X	F1-FE Relationship	F1	FE	The system is removed from operation for maintenance and/or servicing
R1Y	FE-F1 Relationship	FE	F1	The system is restored to full operation following maintenance or servicing.
R1Z	FC-FD Relationship	FD5	FC1	Water flows from water district source to storage.
R1a	C2-F4 Relationship	F2	F4	A sufficiently high hazard index must trigger a fire fighting service request and start a clock measuring response time. This relationship starts the clock.
R1b	F1-F8 Relationship	F1	F8	Command to enable execution of the water deluge when commanded from F5.

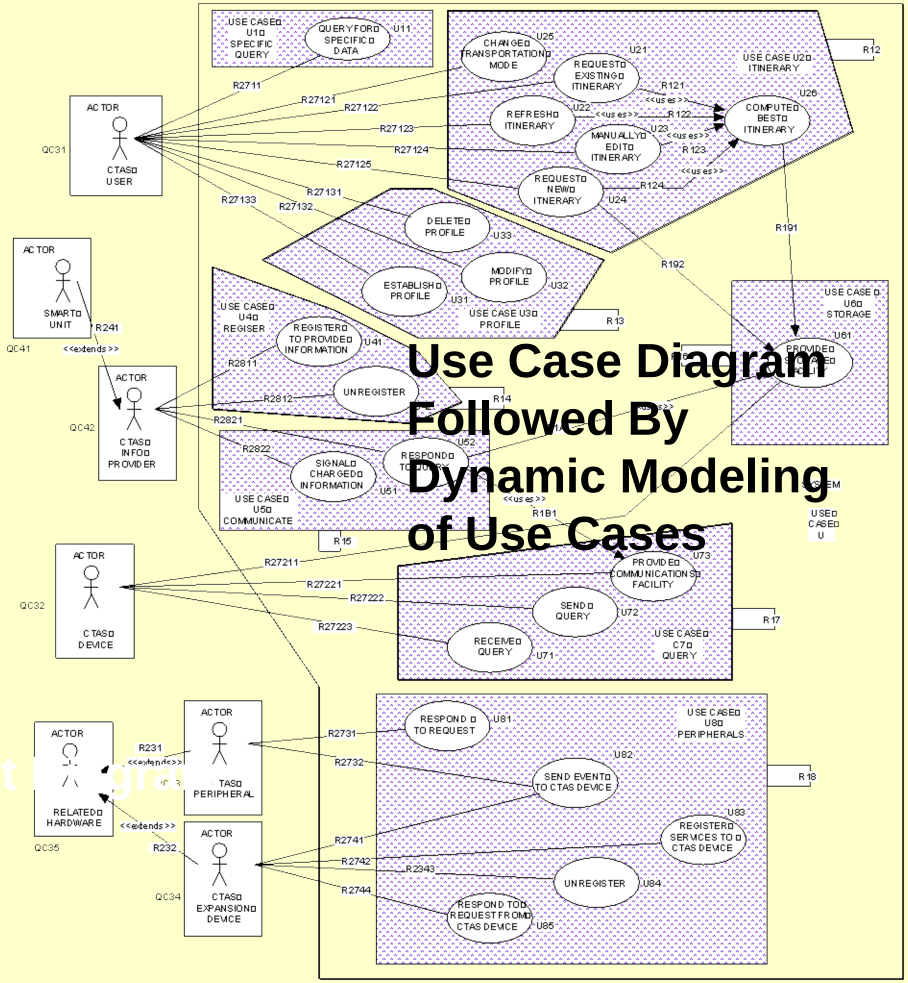
UML/SysML Entry
The Context Diagram Crutch



UML/SysML Dynamic Modeling Overview

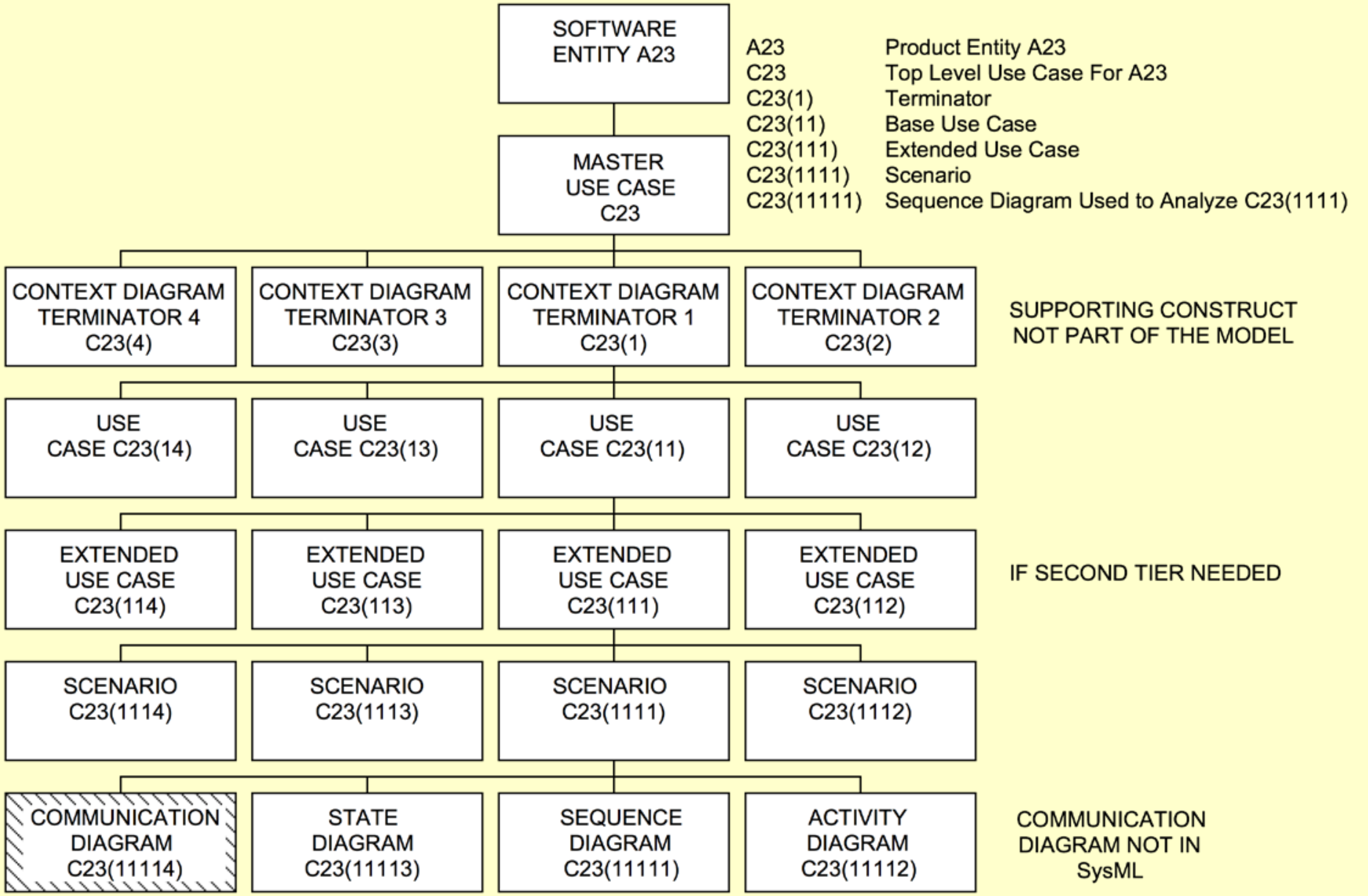


UML/SysML Modeling
Use Case Analysis Example

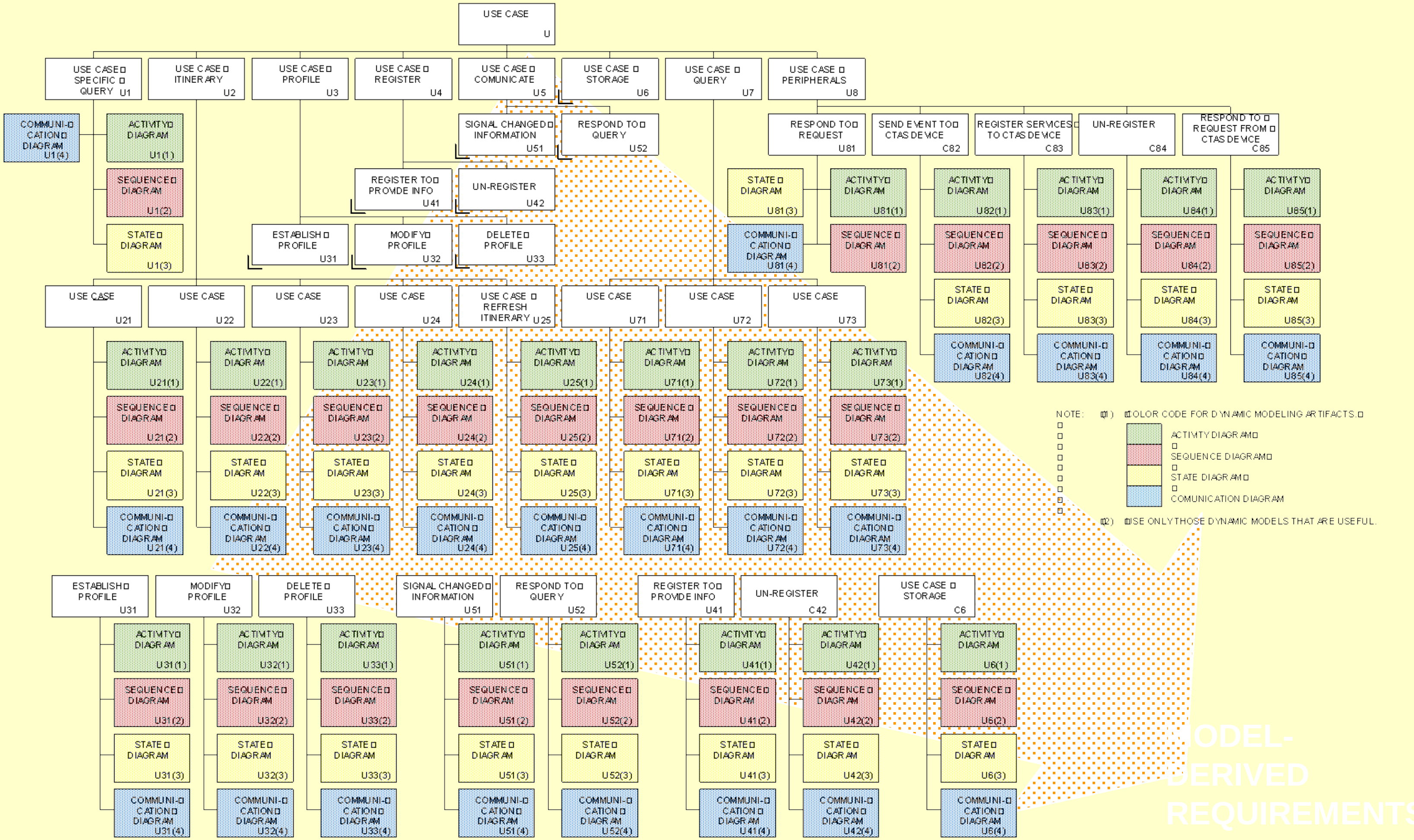


Use Case Diagram Followed By Dynamic Modeling of Use Cases

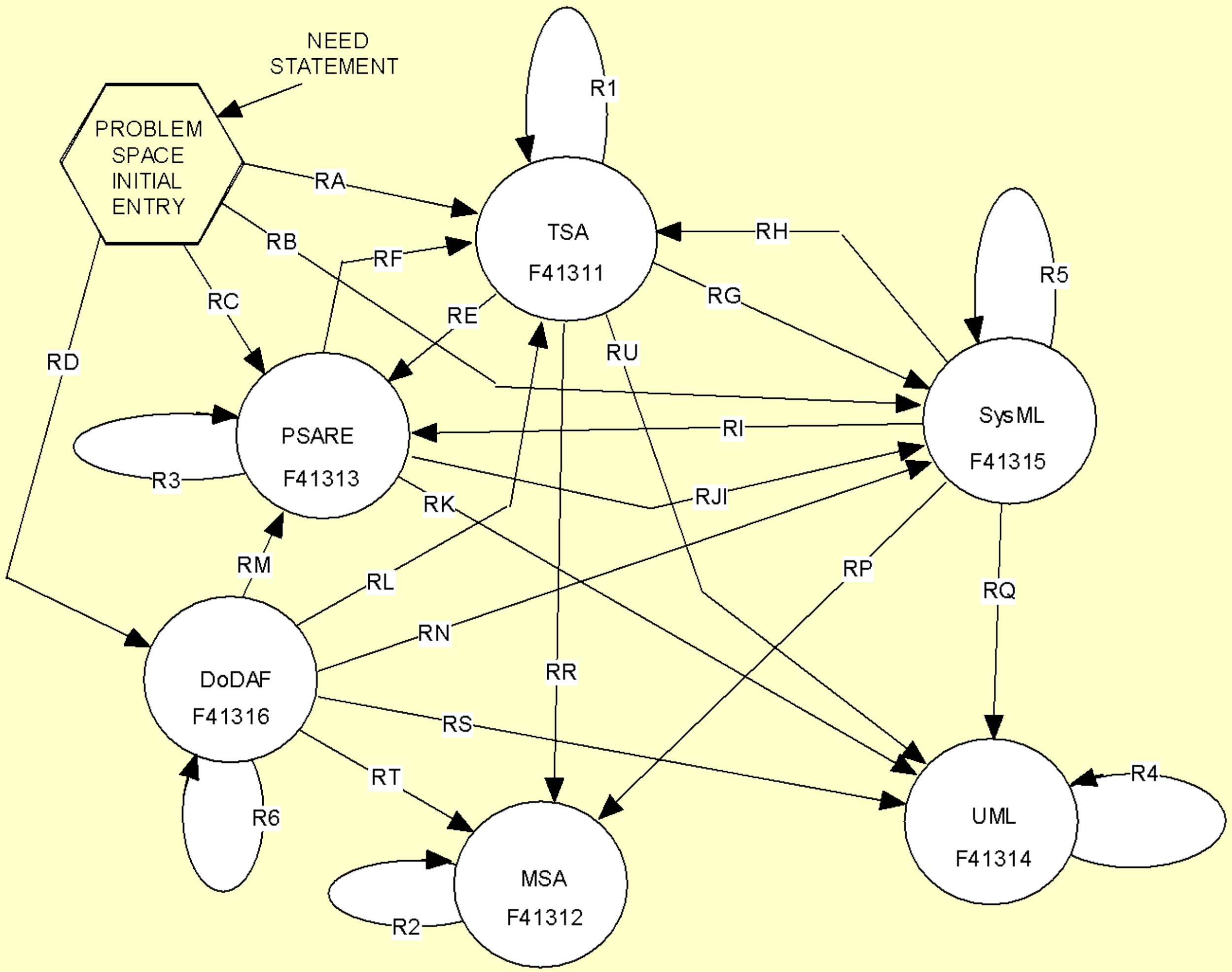
Hierarchical Structure for UML/SysML Analysis



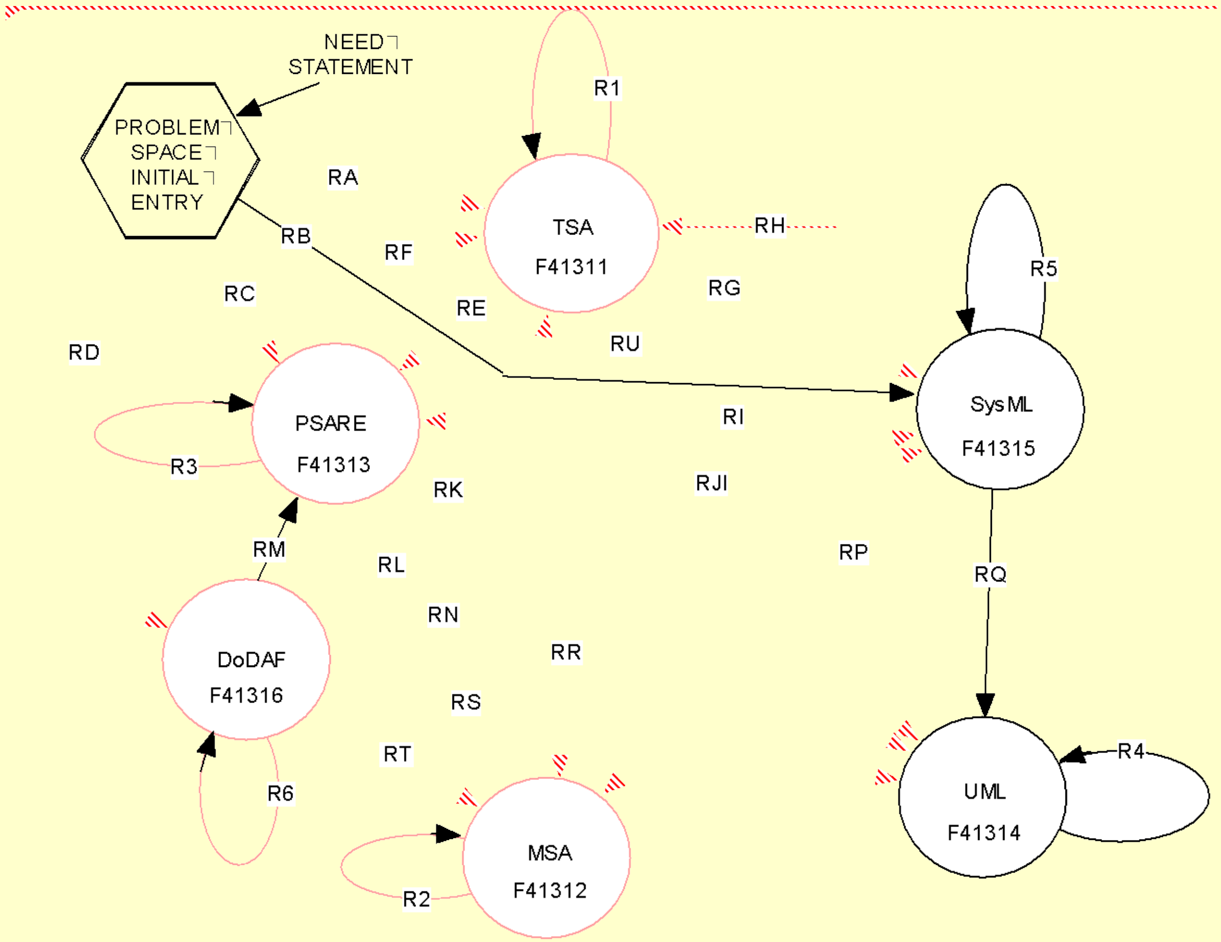
UML/SysML Modeling
Dynamic Modeling Artifacts Example



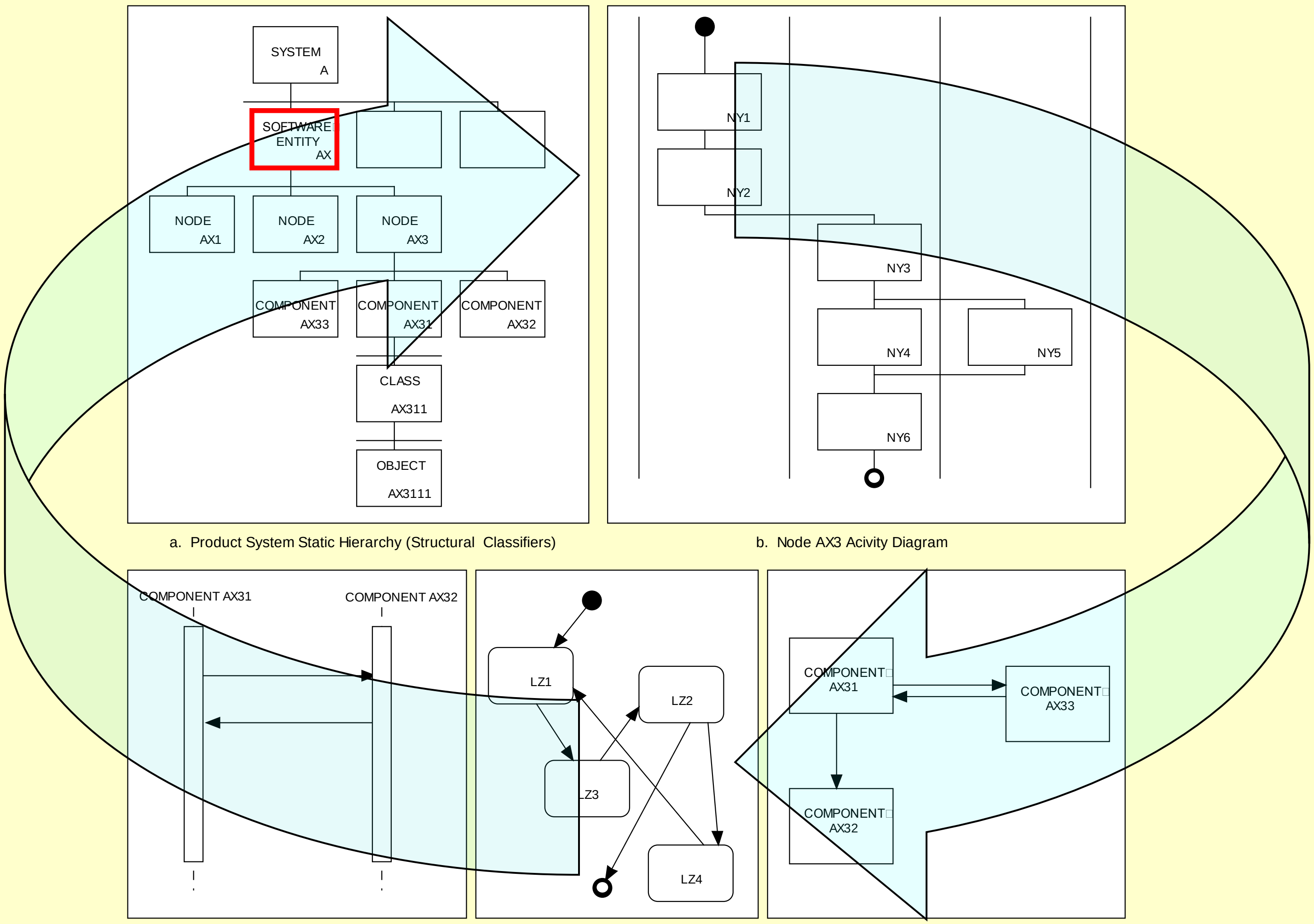
All Possible Inter-Model Transfers



Inter-Model Transfers With a UML/SysML UADF



UML/SysML Cyclical Analysis



a. Product System Static Hierarchy (Structural Classifiers)

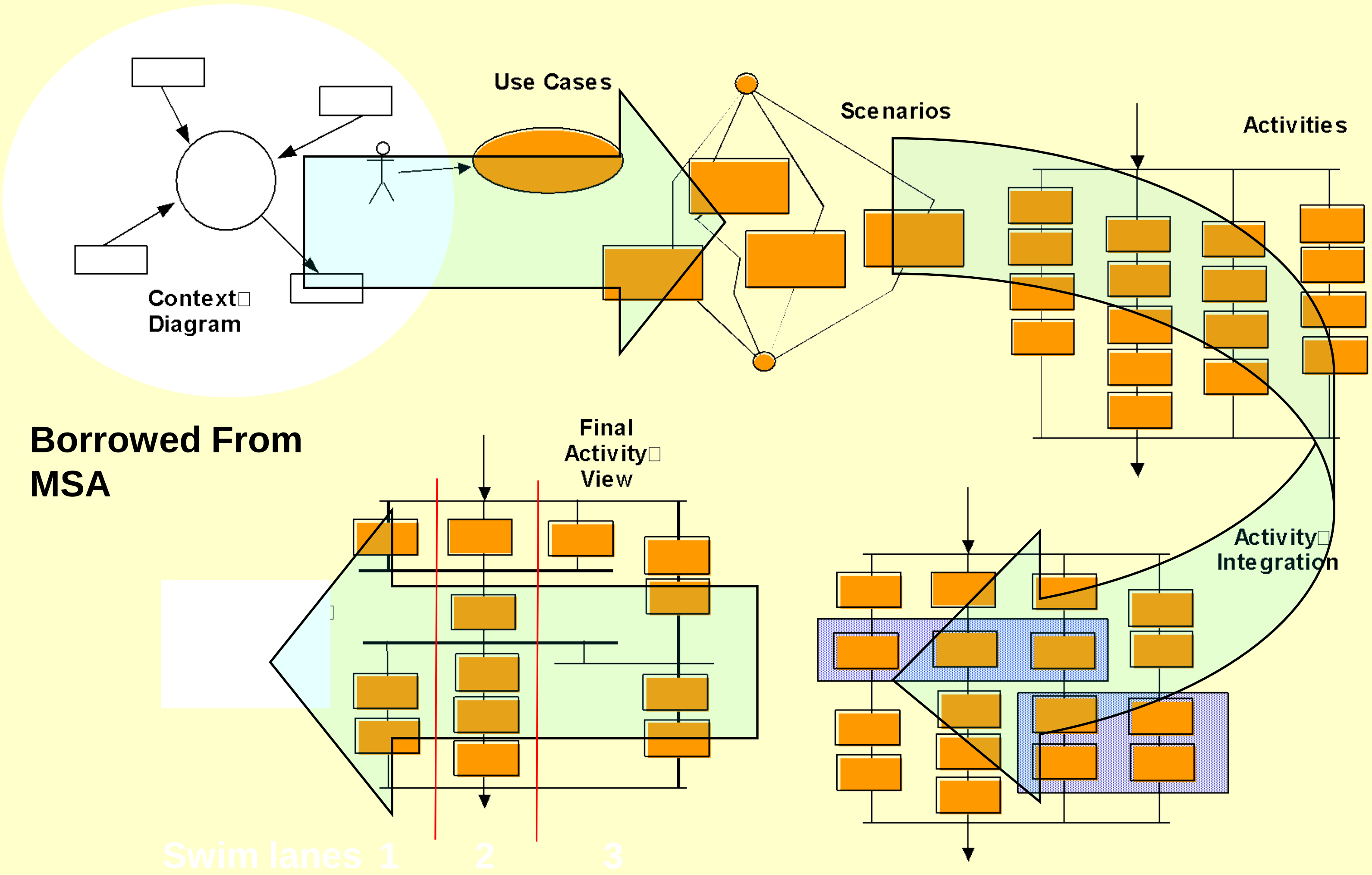
b. Node AX3 Acivity Diagram

c. Node AX3 Sequence Diagram

d. Node AX3 State Diagram

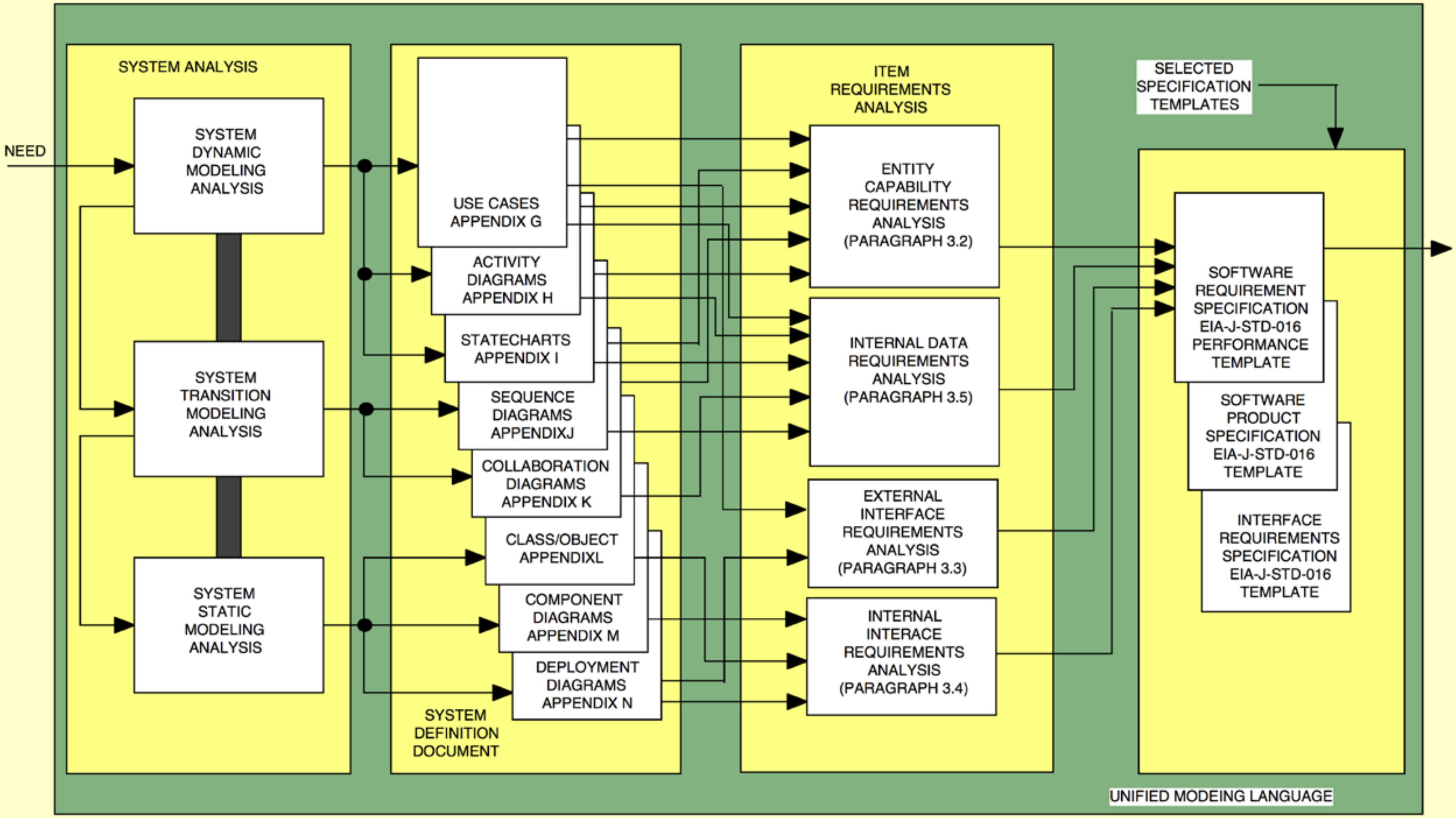
e. Node AX3 Communication Diagram

Entity Identification Using UML/SysML

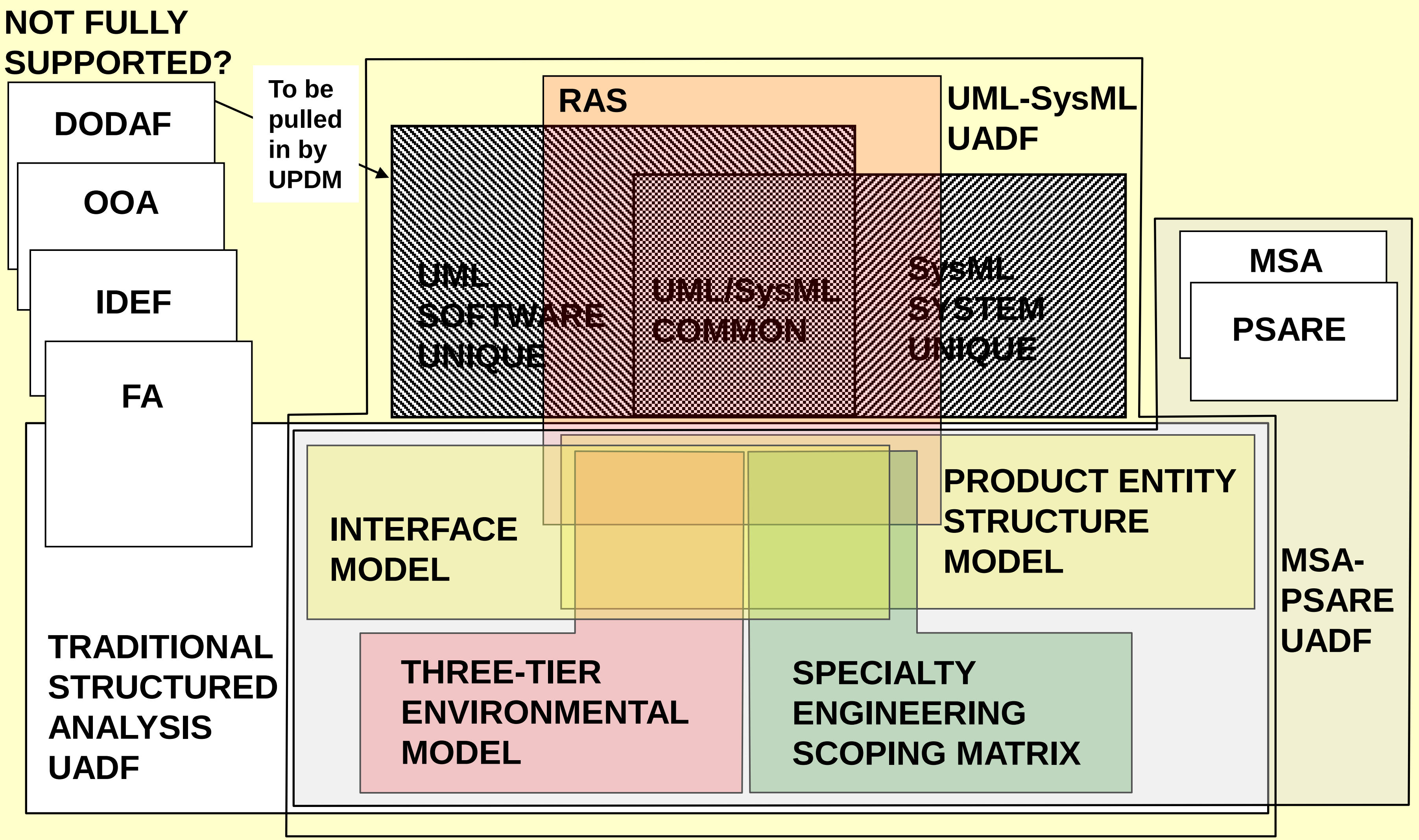


Borrowed From MSA

SAR Organization For UML-SysML



A Universal Model for the Future?



What Will the Future Look Like?

- A single model for the problem space - no matter how the specific product will be developed in hardware or software
- Requirements embedded in problem space models encouraging requirements compliance in design models with the specifications appearing in the form of models
- A connected series of models for design
- Inter-model effects observable directly rather than individual human interpretation of effects followed by conversation and action - can we do this?
- Verification linkage through models
- Eventual connection between the problem space modeling and CAD-CAM models.
- A business process model coordinated with engineering modeling

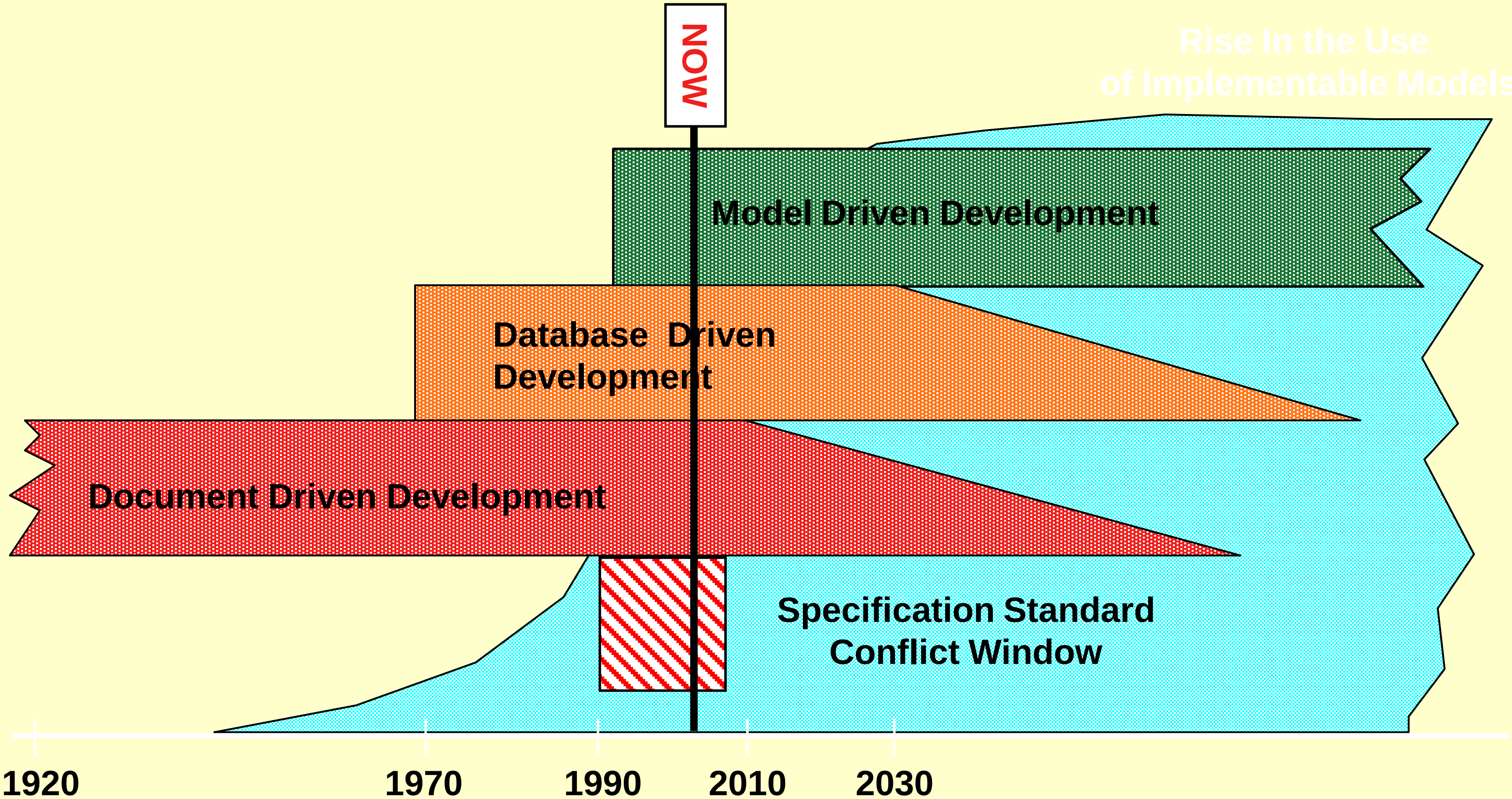
Model-Driven Challenges

- Will it be possible for managers to avoid whiplash due to the speed of the analytical process?
- Can we provide adequate exposure of the on-going and dynamic modeling work to encourage sound management of the development process?
- Will it really be possible to build models that fully express the problem space essential characteristics (requirements) while permitting a solution space larger than a single solution?

The Computer Network Becomes a Team Member in Good Standing

Will there be room for human emotion in the development process? I hope so!

Development Evolution Timeline, Driving Methods Staging



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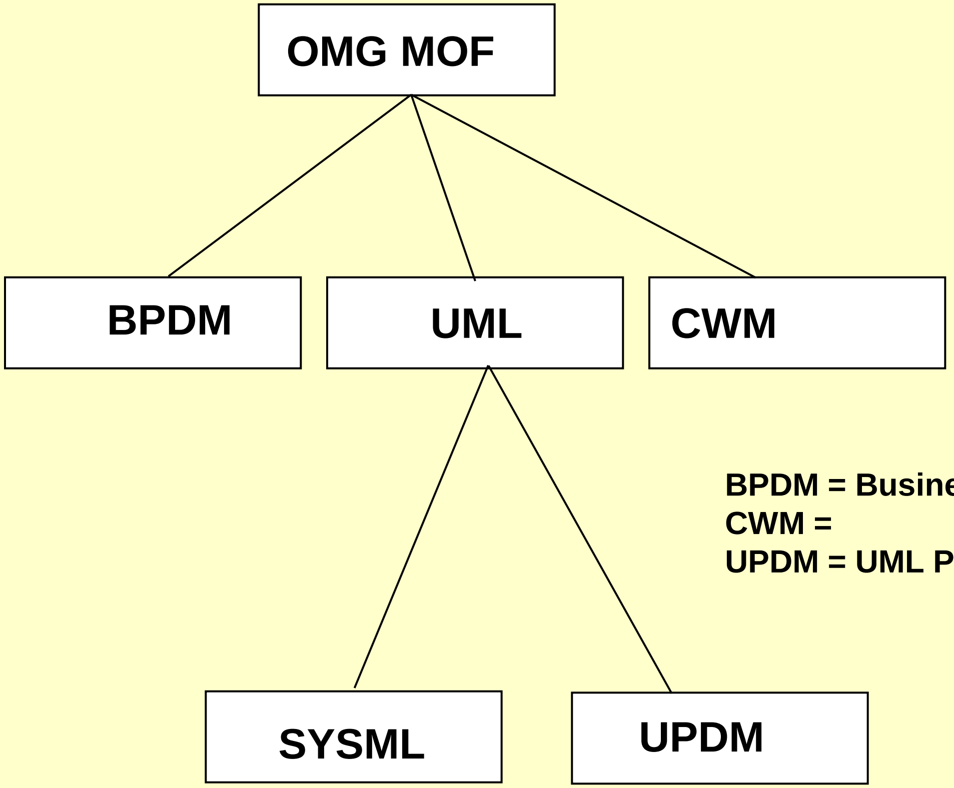
Model Convergence On the Road to Enterprise Architecting



BPDM = Business Process Data Model
CWM =
UPDM = UML Profile For DODAF Modeling

Action Items For You as a System Engineer

- Continue your studies of requirements work
- Come to an understanding about UML and SysML
- Within your company and programs develop modeling skills and work toward simplifying your combined set of models into a universal framework
- Work toward correlating the SW and HW development work patterns so as to encourage more effective integration
- Join INCOSE/NDIA working groups that deal with the issues covered in this paper and offer your ideas.