



# Needs, Requirements, Verification, Validation Lifecycle Manual (NRVVLM) Overview

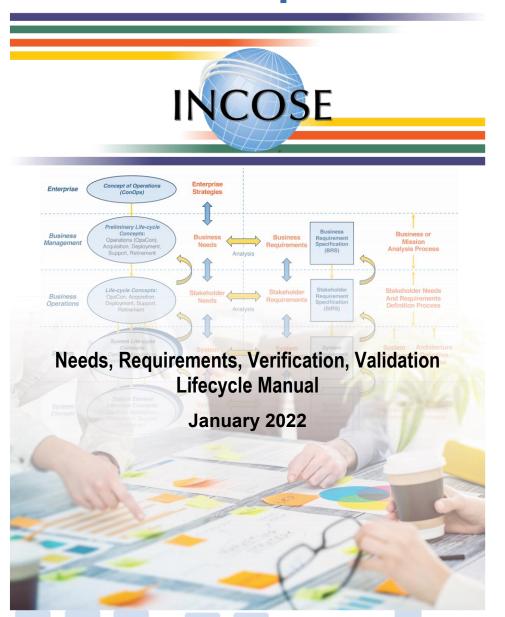
Requirements Working Group

Lou Wheatcraft, Senior Consultant, Wheatland Consulting, LLC

Wheatland.consulting@gmail.com

# The focus of this presentation





### Introduction



- Supplements and elaborates on the INCOSE SE HB
  - Provides more detailed guidance on the what, how, and why concerning needs and requirement definition and management, verification, and validation across the lifecycle.
  - Addresses ambiguity and inconsistencies in ontology concerning needs and requirements definition and management, verification, and validation.
- Presents systems engineering lifecycle concepts from the perspective of needs, requirements, verification, and validation (NRVV) definition and management across the system lifecycle.
- To successfully complete system verification and system validation, the needs and requirements of the system as well as the system verification and system validation artifacts must be managed throughout the entire system lifecycle.
- This Manual provides practical guidance on the activities required to achieve those outcomes.

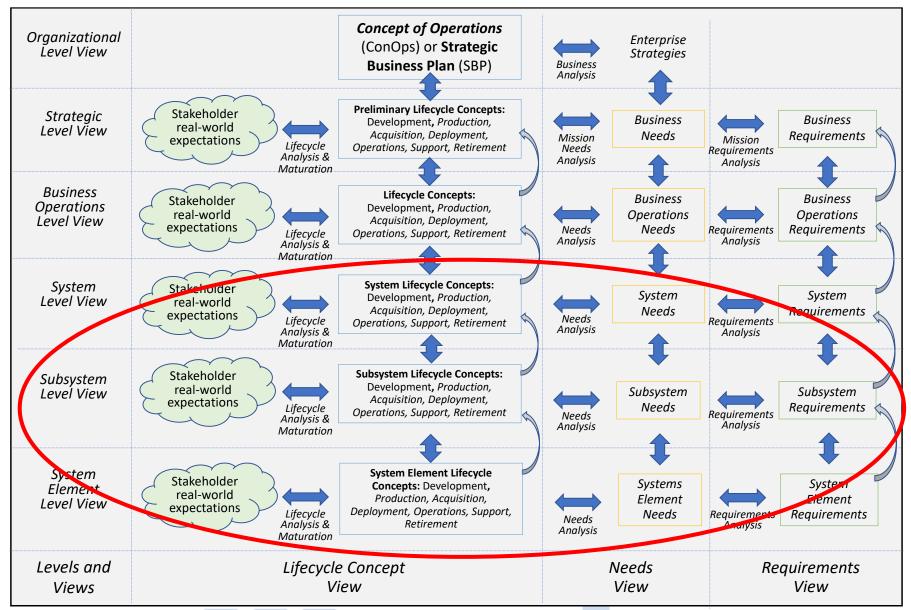
"Needs, Requirements, Verification, and Validation are common threads that tie all lifecycle activities and processes together." Lou Wheatcraft

#### TABLE OF CONTENTS

SECTION 1:	INTRODUCTION	1
1.1	Purpose and Scope	1
1.2	AUDIENCE	
1.3	Approach	3
1.4	NEEDS, REQUIREMENTS, VERIFICATION, AND VALIDATION ACTIVITY AREAS	4
1.5	NEEDS AND REQUIREMENTS LIFECYCLE MANUAL ORGANIZATION	
SECTION 2:	DEFINITIONS AND CONCEPTS	15
2.1	DEFINITIONS	15
2.2	APPLICABILITY OF LIFECYCLE CONCEPTS, NEEDS, AND REQUIREMENTS	18
2.3	LEVELS OF LIFECYCLE CONCEPTS, NEEDS, AND REQUIREMENTS	20
2.3.1	Levels of Organization	
2.3.2	System Architecture – a Hierarchical View	30
2.3.3	System Architecture – a Holistic View	35
2.3.4	Using Both the Hierarchical and Holistic Views	37
2.4	VERIFICATION AND VALIDATION IN CONTEXT	38
2.5	INTEGRATION, VERIFICATION, AND VALIDATION AND THE SE VEE MODEL	45
2.6	SYSTEM VERIFICATION VERSUS REQUIREMENTS VERIFICATION	47
2.7	THE INTENT OF SYSTEM VERIFICATION AND SYSTEM VALIDATION	49
2.8	REDUCING RISK BY ADDRESSING SYSTEM VERIFICATION AND SYSTEM VALIDATION EARLY IN THE LIFECYCLE	51
2.9	IMPORTANCE OF AN INTEGRATED, COLLABORATIVE PROJECT TEAM	54
2.10	IMPORTANCE OF EFFECTIVE COMMUNICATIONS	
2.11	GREEN FIELD VERSUS BROWN FIELD SYSTEMS	60
2.12	AVOIDING TECHNICAL DEBT	61
2.13	OVERVIEW OF SYSTEMS ENGINEERING AS DISCUSSED IN THIS MANUAL.	63
SECTION 3:	INFORMATION-BASED NEEDS AND REQUIREMENT DEVELOPMENT AND MANAGEMENT	67
3.1	Information-Based Needs and Requirements Definition and Management	68
3.2	KEY CHARACTERISTICS OF THE I-NRDM APPROACH	72
3.3	TEXTUAL NEEDS AND REQUIREMENTS VERSUS MODELS AND DIAGRAMS	75
3.3.1	Textual Needs and Requirements	75
222	Models and Diagrams	77

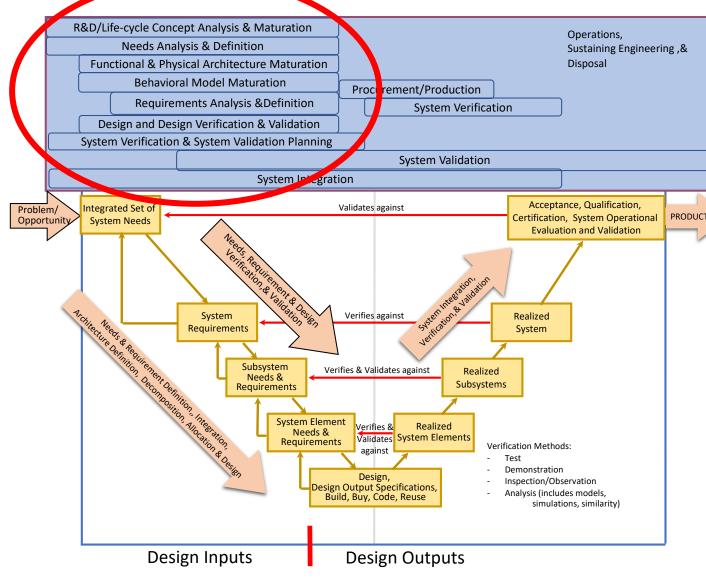


# Levels of Lifecycle Concepts, Needs, & Requirements



Focus of this Manual

# SE Processes are Intended to be Practiced Concurrently



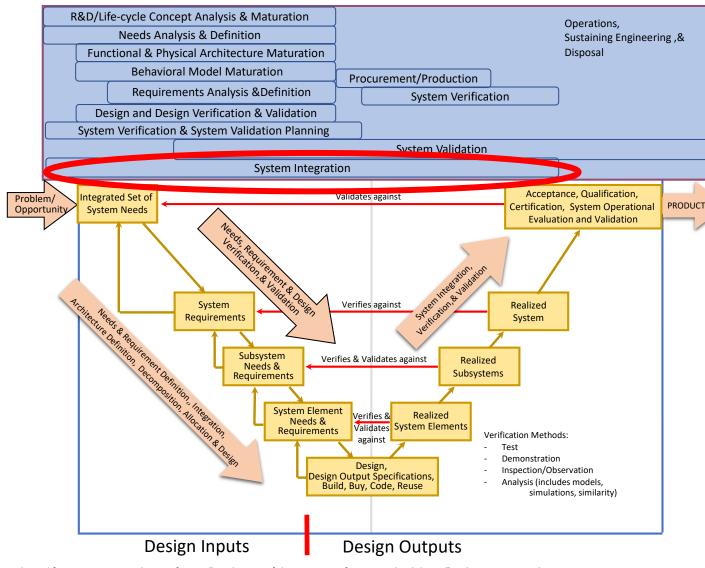
Concurrent definition, analysis, and maturation applied iteratively and recursively as we move down the left side of the SE Vee

Faster and cheaper than classical waterfall/serial, document-centric processes with silos

Aids in establishing correctness, completeness, and consistency, of all SE artifacts

# The System Engineering "Vee" Revisited



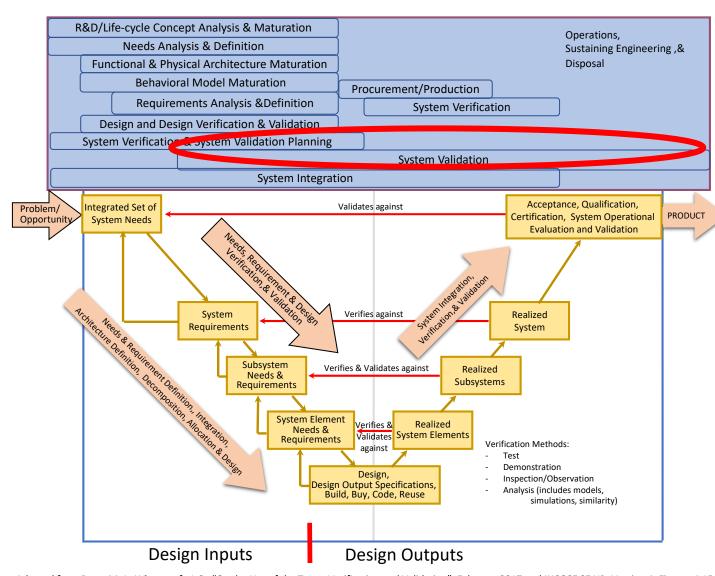


System Integration should <u>not</u> be thought of as only occurring on the right side of the SE Vee during IV&V

The integrated SOI must be managed from the beginning of the project across all lifecycle stages

The customer/supplier relationship must allow management of the integrated SOI

# Validation Across the Lifecycle



Validation should <u>not</u> be thought of as only occurring on the right side of the SE Vee during system integration, verification, and validation

Validation is done across the system lifecycle:

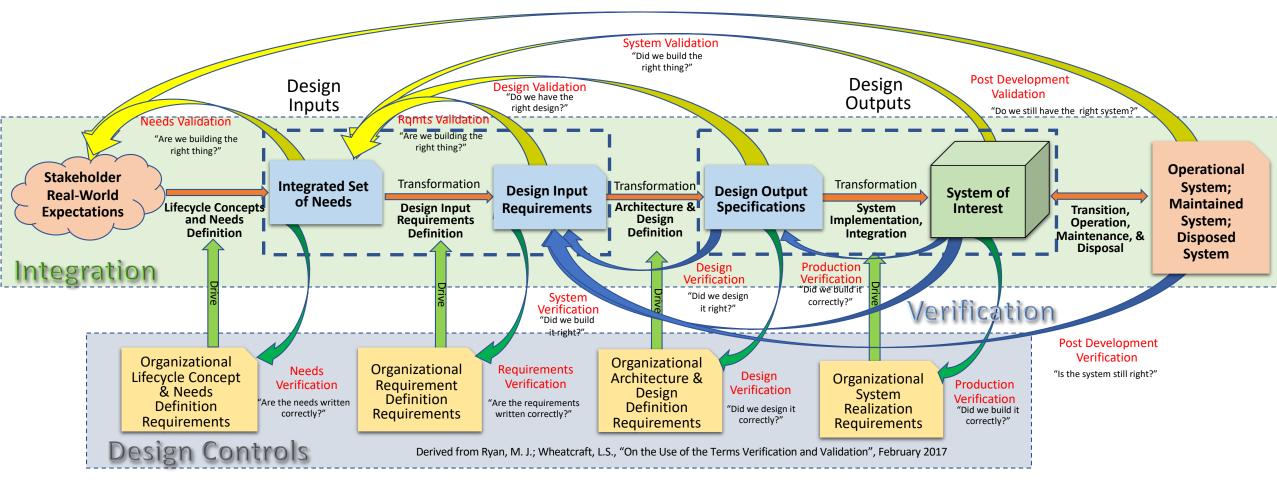
- Needs
- Design Input Requirements
- Architecture
- Design
- Design Output Specifications
- Realized system elements, subsystems, & the integrated SOI

Validation on the left side of the SE Vee decreases issues on the right side of the SE Vee

Adapted from Ryan, M. J.; Wheatcraft, L.S., "On the Use of the Terms Verification and Validation", February 2017 and INCOSE SE HB, Version 4, Figures 4.15 & 4.19

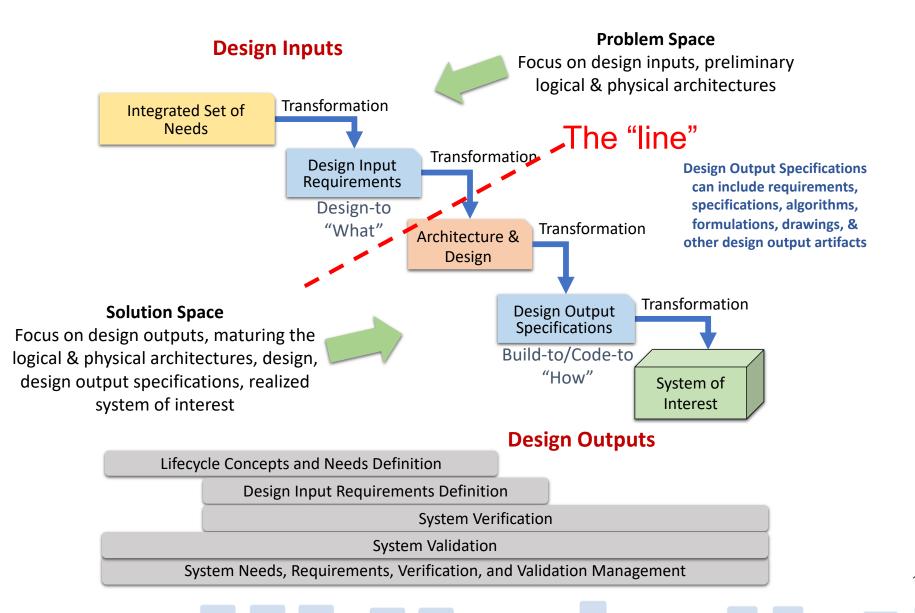


#### Validation



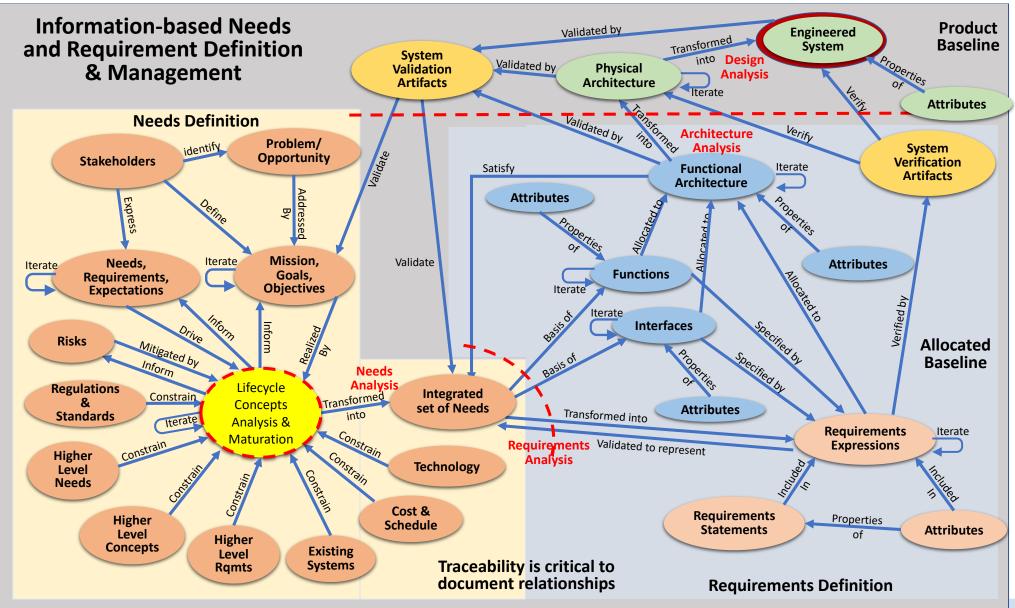
# Design Inputs vs Design Outputs





# Data-Centric Practice of Systems Engineering





# Needs vs Requirements



- Needs represent the stakeholder, customer/acquirer, user view of the system
  - What do the stakeholders need the system to do that will result in their problem to be solved or opportunity to be realized within defined constraints?
  - Communicates the stakeholder expectations for the end-state once the System is delivered – in the end what will make the customer(s) happy?
  - The system will be <u>validated</u> against its <u>integrated set of needs</u>
- Requirements represent the technical, developer view of the system
  - What must the system do in order to meet the needs?
  - Needs are transformed into design input requirements that will result in a design that will implement that need
  - The system will be <u>verified</u> against its <u>design input requirements</u>



# Rather than just focusing on the requirements, we must focus on both needs and requirements!!

Rather than just focusing on verification that the requirements are met, we must also focus on validation that the needs are met!!

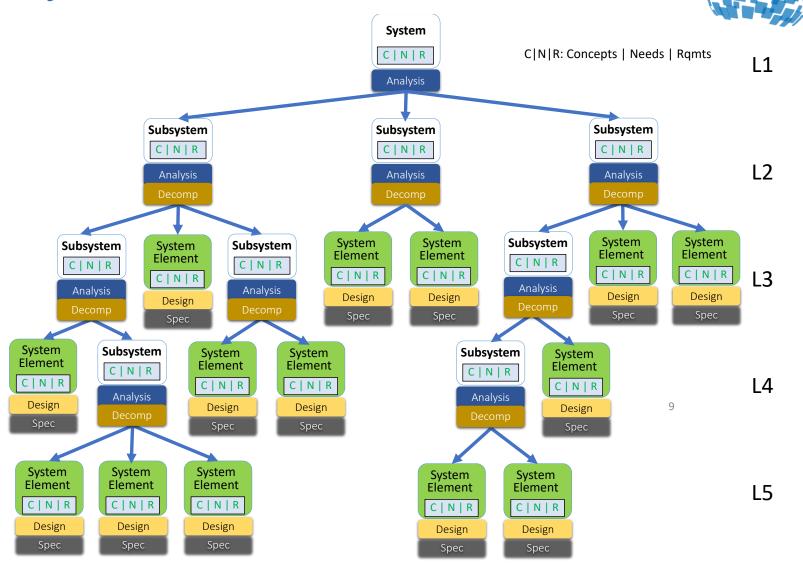
Needs, requirements, verification, and validation are the common treads that tie all SE lifecycle activities and artifacts together.

From a holist view of SE, needs, requirements, verification, and validation must be managed in the context of all other SE process areas rather than in silos distinct from the other process areas.

# Levels of a System - Hierarchical View

Focus on decomposition makes it easier to develop the SOI in bite sized chunks across multiple organizational units (internal and external) based on specialize knowledge and expertise

Lifecycle concepts, needs, and requirements should be defined for the system as well as each subsystem and system element that is part of the system architecture

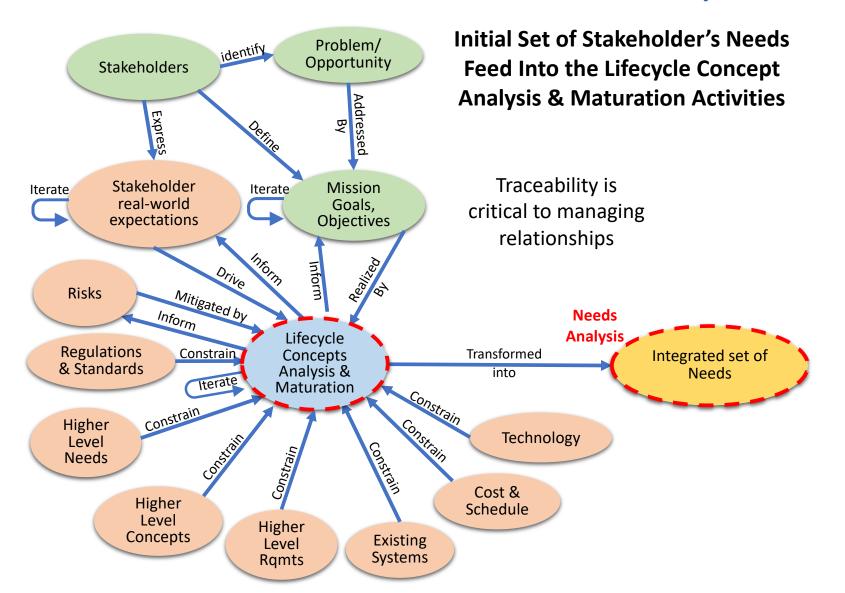


# **Table of Contents**

E	CTION 4:	LIFECYCLE CONCEPTS AND NEEDS DEFINITION	80
	4.1	PREPARE FOR LIFECYCLE CONCEPTS AND NEEDS DEFINITION	85
	4.2	DEFINE INPUTS TO LIFECYCLE CONCEPTS ANALYSIS AND MATURATION	86
	4.2.1	Define the Problem, Threat, or Opportunity	86
	4.2.2	Define Mission, Goals, Objectives, and Measures	87
	4.2.3	Identify External and Internal Stakeholders	93
	4.2.4	Elicit Stakeholder needs and Stakeholder-owned System Requirements	99
	4.2.5	Document Elicitation Outcomes	107
	4.2.6	Identify Drivers and Constraints	110
	4.2.7	Identify, Assess, and Handle Risks	121
	4.3	CAPTURE PRELIMINARY INTEGRATED SET OF LIFECYCLE CONCEPTS	128
	4.3.1	Perspectives	129
	4.3.2	ConOps versus OpsCon	
	4.3.3	Get Stakeholder Agreement	131
	4.4	LIFECYCLE CONCEPTS ANALYSIS AND MATURATION	132
	4.4.1	Feasibility	133
	4.4.2	Design as Part of the Lifecycle Analysis and Maturation Activities	134
	4.4.3	Use of Diagrams and Models for Analysis	134
	4.4.4	Levels of Detail and Abstraction	141
	4.4.5	Completeness	
	4.4.6	Risk Assessment	144
	4.4.7	Iteration to Mature Lifecycle Concepts	147
	4.5	Define and Record the Integrated Set of Needs	
	4.5.1	People and Process Needs	155
	4.5.2	Define the Integrated Set of Needs	157
	4.5.3	Record the Integrated Set of Needs	
	4.6	PLAN FOR SYSTEM VALIDATION	
	4.7	BASELINE AND MANAGE LIFECYCLE CONCEPTS AND NEEDS DEFINITION OUTPUTS	168

# **Needs Before Requirements**

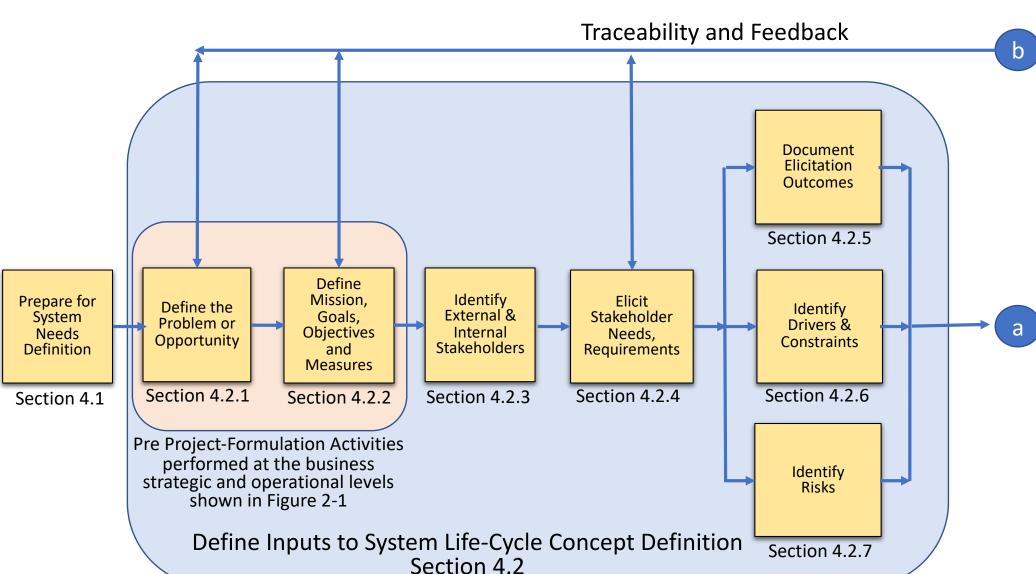




There is a lot of work to be done BEFORE defining requirements!

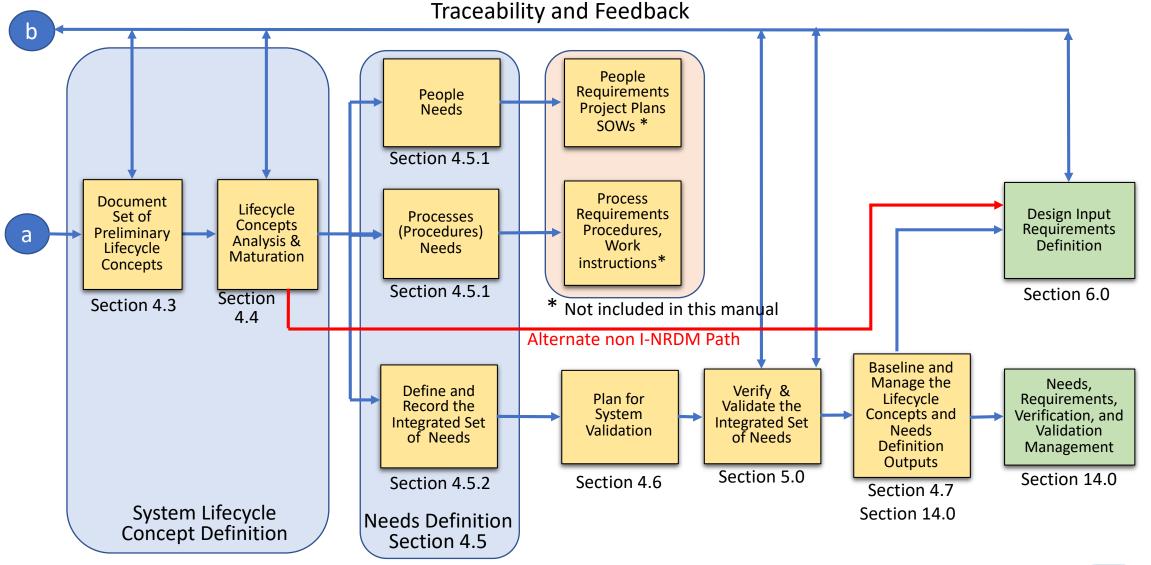
Establish completeness, consistency, correctness, and feasibility before defining needs and transforming them into the design input requirements

# Lifecycle Concept and Needs Definition Part 1

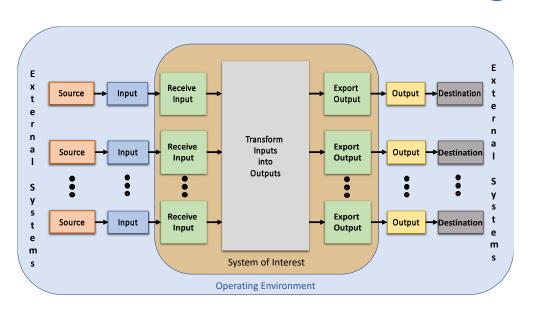


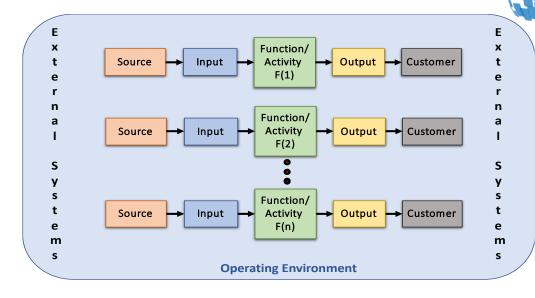
# Lifecycle Concept and Needs Definition Part 2

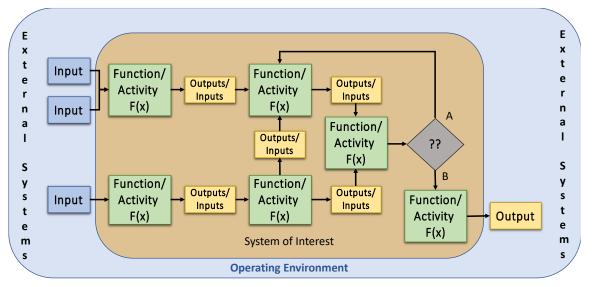


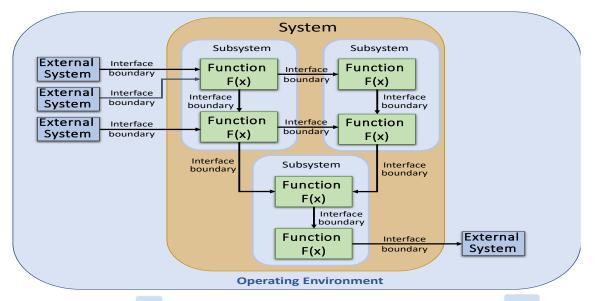


# Use of Diagrams and Models









# Zeroing in on a Feasible Set of Lifecycle Concepts



Preliminary set of lifecycle concepts Section 4.3

> Iteration -Increase Resolution

Model development, analysis, and maturation
Section 4.4.7.1

Feasible life-cycle concepts, integrated set of system needs, preliminary physical architecture, models, plans, budgets, schedules

"Zero In" on an initial physical architecture and corresponding set of life-cycle concepts

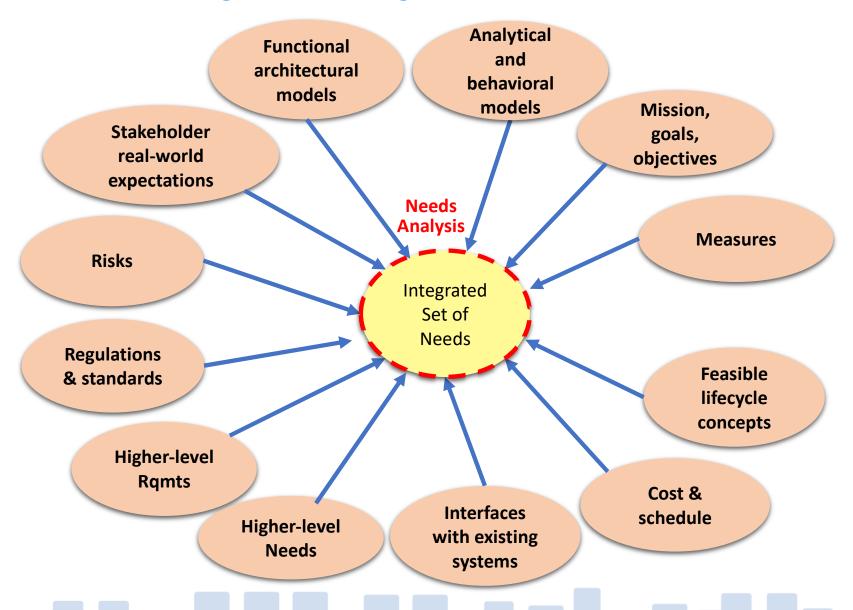
Section 4.4.7.4

Trade space define candidate
physical
architectures
Section 4.4.7.2

Physical architecture – feasibility analysis, technology readiness assessment, risk assessments, trade studies Section 4.4.7.3

# Defining the Integrated Set of Needs





### Table of Contents

E	ECTION 5: N	IEEDS VERIFICATION AND NEEDS VALIDATION	170
	5.1 NEEDS	Verification	171
	5.1.1	Prepare for Needs Verification	172
	5.1.2	Perform Needs Verification	173
	5.1.3	Manage Needs Verification Results	175
	5.2 N	EEDS VALIDATION	175
	5.2.1	Prepare for Needs Validation	176
	5.2.2	Perform Needs Validation	177
	5.2.3	Manage Needs Validation Results	178
	5.3 U	SE OF ATTRIBUTES TO MANAGE NEEDS VERIFICATION AND NEEDS VALIDATION	179

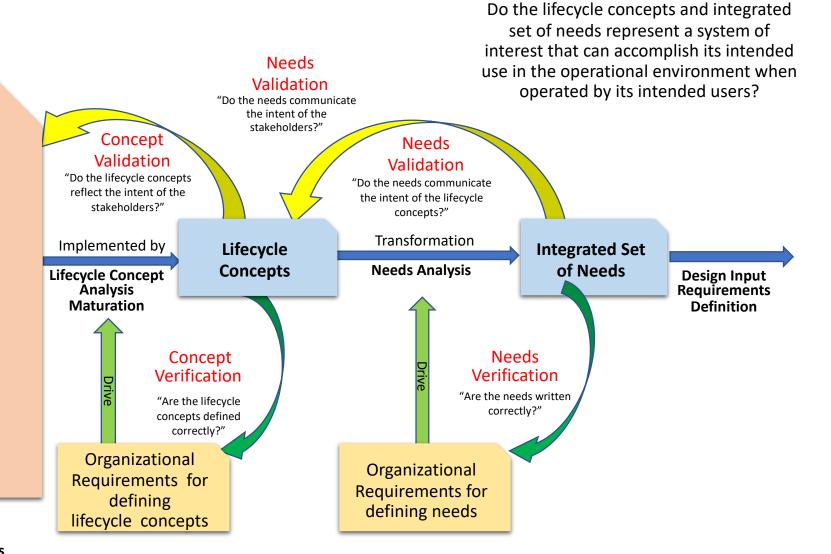
- Do the individual need expressions have the characteristics defined in the INCOSE GfWR: Necessary, Appropriate, Unambiguous, Complete, Singular, Feasible, Verifiable, Correct, and Conforming?
- Does the integrated set of system needs have the characteristics defined in the INCOSE GfWR: Complete, Consistent, Feasible, Comprehensible, Able to be validated?
- Have attributes been defined for each need statement?
- Are all need statements traceable to their source?
- Does the integrated set of system needs clearly communicate the stakeholder expectations concerning the intended use of the SOI in its operational environment by its intended users?

# **Needs Verification and Validation**

Problem or opportunity

- MGOs
- Measures
- Stakeholder real-world expectations
- Use cases, user stories, system concepts, OpsCon, ConOps
- Higher level Needs
- Higher level Requirements
- Higher level lifecycle concepts
- Drivers & constraints,
  - External systems
  - Standards
  - Regulations
  - Technology
  - Operating Environment
- Risks

Business & Mission Analysis and Stakeholder Needs and Requirements Definition Processes

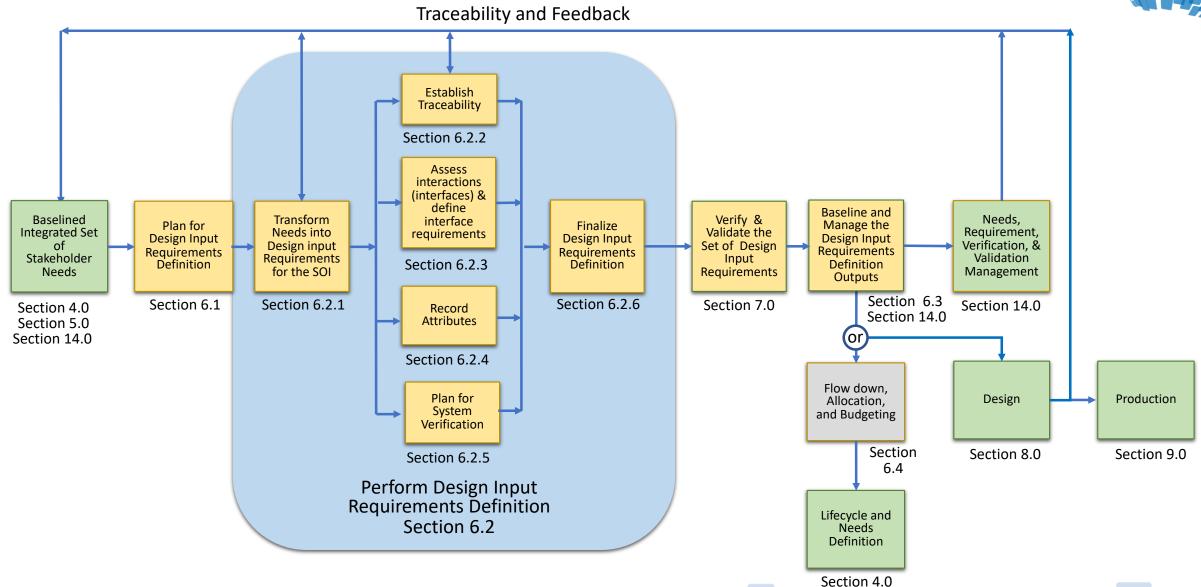


# **Table of Contents**

SECTION 6:	DESIGN INPUT REQUIREMENTS DEFINITION	180
6.1	PREPARE FOR DESIGN INPUT REQUIREMENTS DEFINITION	181
6.2	PERFORM DESIGN INPUT REQUIREMENTS DEFINITION	182
6.2.1	Transforming SOI Needs into SOI Design Input Requirements	184
6.2.2	Establish Traceability	204
6.2.3	Defining Interactions and Recording Interface Requirements	211
6.2.4	Use of Attributes to Develop and Manage Design Input Requirements	231
6.2.5	Plan for System Verification	232
6.2.6	Finalize Design Input Requirements Definition	234
6.3	BASELINE AND MANAGE DESIGN INPUT REQUIREMENTS	240
6.4	ARCHITECTURAL LEVELS, FLOW DOWN, ALLOCATION, AND BUDGETING	241
6.4.1	Moving Between Levels of the Physical Architecture	242
6.4.2	Product Breakdown Structure and Document Tree	242
6.4.3	Allocation – Flow Down of Requirements	245
6.4.4	Defining Children Requirements That Meet the Intent of the Allocated Parents	251
6.4.5	Budgeting of Performance, Resources, and Quality Requirements	253
6.4.6	Budget Management: Margins and Reserves	256
6.4.7	Use of Traceability and Allocation to Manage Requirements	258
6.5	SUMMARY OF DESIGN INPUT REQUIREMENTS DEFINITION	259

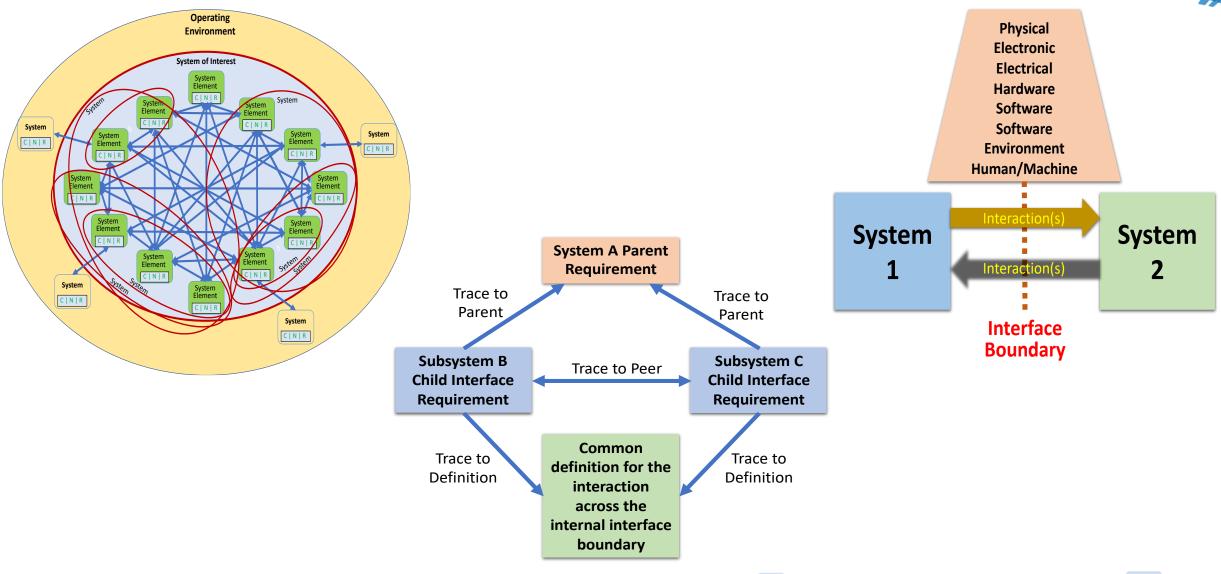
# Defining Design Input Requirements



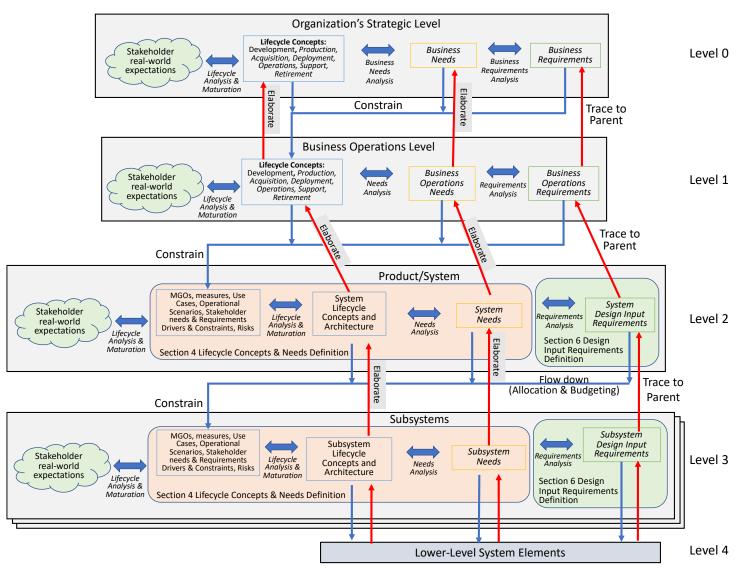


# Assessing Interactions Across Interface Boundaries





# Moving Down the System Architecture



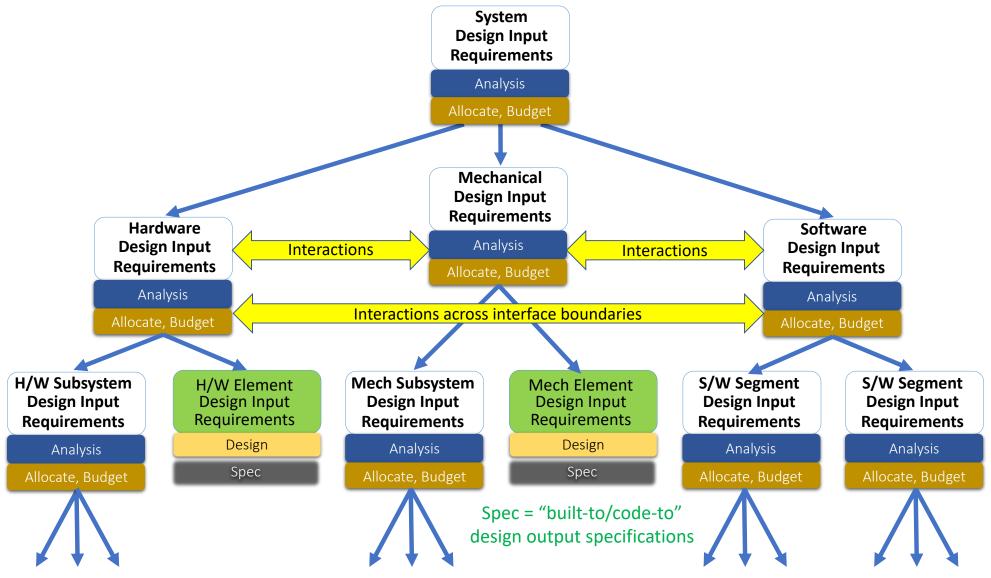
Requirements at one level are allocated/budgeted to the subsystems and system elements at the next level

These requirements are inputs to the lifecycle concepts, needs, and requirements definition process for each of the subsystems and system elements to which the requirements were allocated/budgeted

Process repeats until a buy, build, code, or reuse decision is made.

# Alternate Architecture for Software Centric Systems





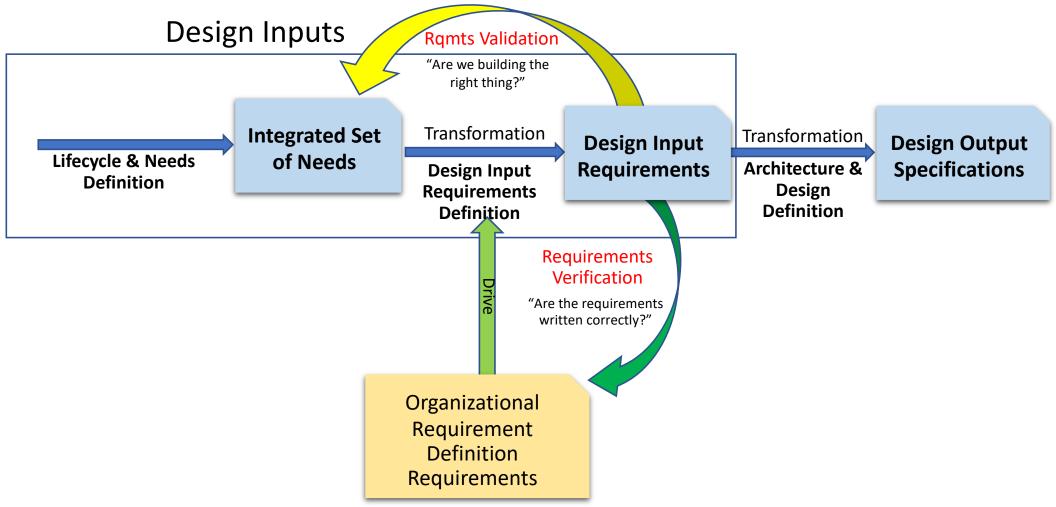
### Table of Contents

E	CTION 7	: DESIGN INPUT REQUIREMENTS VERIFICATION AND VALIDATION	260
	7.1	DESIGN INPUT REQUIREMENTS VERIFICATION	262
	7.1.1	Prepare for Design Input Requirements Verification	262
	7.1.2	Perform Design Input Requirements Verification	264
	7.1.3	Manage Design Input Requirements Verification Results	266
	7.2	DESIGN INPUT REQUIREMENTS VALIDATION	267
	7.2.1	Prepare for Design Input Requirements Validation	267
	7.2.2	Perform Design Input Requirements Validation	268
	7.2.3	Manage Design Input Requirements Validation Results	270
	7.3	Use of Attributes to Manage Requirements Verification and Validation	271

- Do the individual requirement expressions have the characteristics defined in the INCOSE GfWR: Necessary, Appropriate, Unambiguous, Complete, Singular, Feasible, Verifiable, Correct, and Conforming?
- Does the set of design input requirements have the characteristics defined in the INCOSE GfWR: Complete, Consistent, Feasible, Comprehensible, Able to be validated?
- Have attributes been defined for each requirement statement?
- Are all requirement statements traceable to their parent, source, or dependent peer requirements?
- Does the set of design input requirements communicate the intent of the integrated set of system needs from which they were transformed?

# Requirements Verification and Validation





Derived from Ryan, M. J.; Wheatcraft, L.S., "On the Use of the Terms Verification and Validation", February 2017

# **Table of Contents**



SECTION 8:	DESIGN VERIFICATION AND DESIGN VALIDATION	272
8.1	DESIGN DEFINITION PROCESSES OVERVIEW	273
8.2	EARLY SYSTEM VERIFICATION AND SYSTEM VALIDATION	276
8.3	VALIDATION OF THE SYSTEM VERIFICATION AND SYSTEM VALIDATION ARTIFACTS	278
8.4	DESIGN VERIFICATION	279
8.4.1	Prepare for Design Verification	281
8.4.2		
8.4.3	Manage Design Verification Results	283
8.5	DESIGN VALIDATION	
8.5.1	Prepare for Design Validation	285
8.5.2		
8.5.3	Manage Design Validation Results	287
8.6	Use of Attributes to Manage Design Verification and Design Validation	
SECTION 9:	PRODUCTION VERIFICATION	289

# Design



Integrated set of needs,
design input requirements,
preliminary physical architecture,
lifecycle concepts, models, prototypes,
plans, budgets, and schedules

Iteration - System analysis, characterization, & optimization

Baselined physical architecture, design-output specifications, lifecycle concepts, models, plans, budgets, schedules

"Zero In" on the physical architecture, design concepts, updated lifecycle concepts, and artifacts

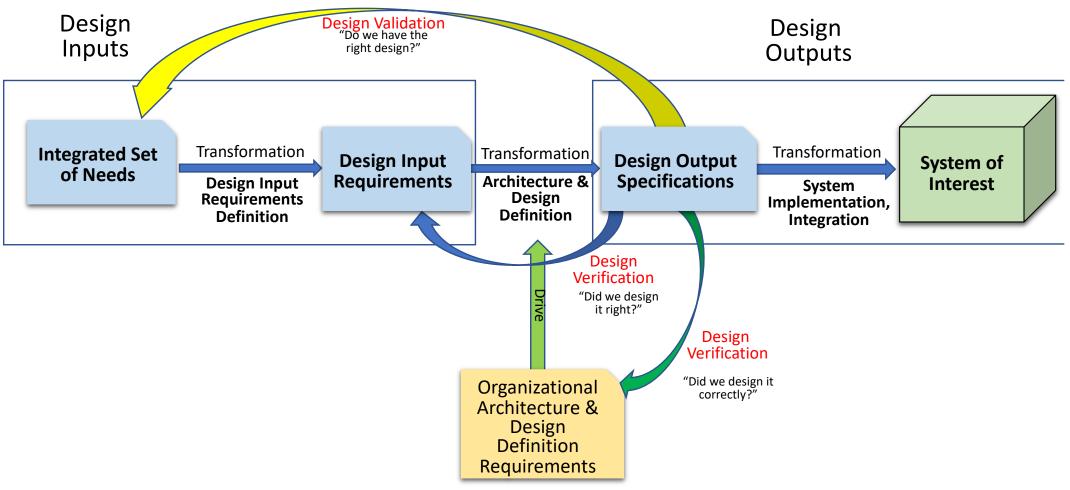
Model refinement and analysis

Trade space – mature the physical design using models, simulations, prototypes, engineering test units, technology readiness assessment, risk assessments, trade studies

Physical architecture and design perform functional, performance, quality, compliance, and behavioral analysis, and design V&V

# Design Verification and Validation



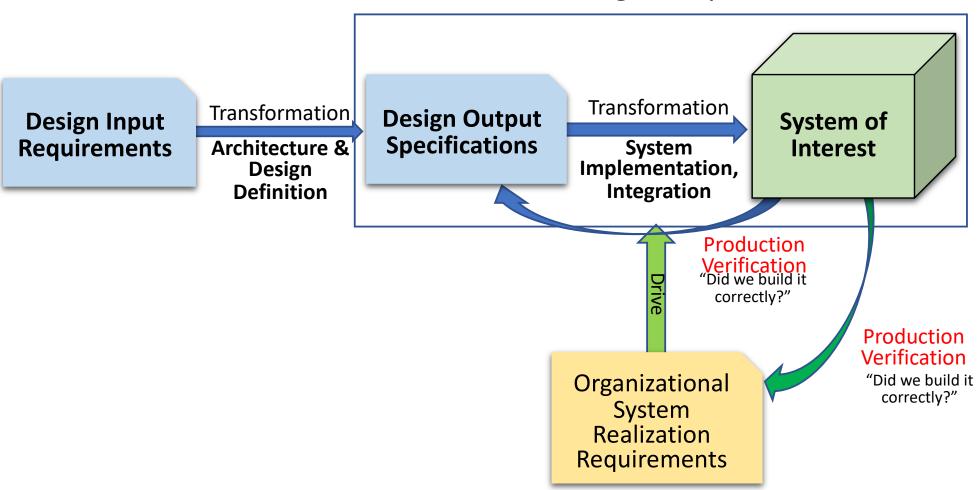


Derived from Ryan, M. J.; Wheatcraft, L.S., "On the Use of the Terms Verification and Validation", February 2017

### Production Verification and Validation



### **Design Outputs**



Derived from Ryan, M. J.; Wheatcraft, L.S., "On the Use of the Terms Verification and Validation", February 2017

# **Table of Contents**

ECTION 10:	SYSTEM VERIFICATION AND SYSTEM VALIDATION COMMON PRINCIPLES	294
10.1 P	LANNING STAGE	297
10.1.1	Define the System Verification and System Validation Success Criteria	299
10.1.2	Determine the System Verification and System Validation Strategy	304
10.1.3	Select a System Verification and System Validation Method	317
10.1.4	System Verification and System Validation Matrices	330
10.1.5	System Verification and System Validation Description Sheets	332
10.2 D	EFINING STAGE	335
10.2.1	System Verification and System Validation Activity Definition Sheets	335
10.2.2	System Verification and System Validation Procedure Requirements Definition	338
10.2.3	System Verification or System Validation Procedure Development	341
10.3 E	XECUTION STAGE: PERFORMING THE SYSTEM VERIFICATION AND SYSTEM VALIDATION PROCEDURES	343
10.3.1	Formal System Verification or System Validation Event Representative Process	345
10.3.2	Discrepancies and Non-conformances	347
10.3.3	Variances, Concessions, Waivers, and Deviations	348
10.4 R	EPORTING STAGE: DOCUMENTING THE RESULTS	
10.4.1	Chain of Evidence Showing Conformance or Compliance	352
10.4.2	Use of Compliance Matrices	353
10.5 A	PPROVING STAGE: SYSTEM APPROVAL	354
10.6 U	SE OF ATTRIBUTES TO MANAGE SYSTEM VERIFICATION AND SYSTEM VALIDATION ACTIVITIES	356
10.7 N	AAINTAINING THE SYSTEM VERIFICATION AND SYSTEM VALIDATION ARTIFACTS	357
ECTION 11:	SYSTEM VERIFICATION AND SYSTEM VALIDATION PROCESSES	359
11.1 S	YSTEM VERIFICATION PROCESS	361
11.1.1	Prepare for System Verification – Planning and Defining	363
11.1.2	Perform System Verification Activities - Executing	<i>36</i> 3
11.1.3	Manage System Verification results – Reporting and Approving	364
11.2 S	YSTEM VALIDATION PROCESS	365
11.2.1	Prepare for System Validation – Planning and Defining	367
11.2.2	Perform System Validation Activities - Executing	368
11.2.3	Manage System Validation Results	369



# System Verification & System Validation Stages



# Needs, Design Input Requirements for each architectural entity

#### **Planning Stage**

- Define a verification or validation Instance for each need and design input requirement for each system and system element that are part of the physical architecture
- Define validation attributes for each need and verification attributes or each requirement:
- Success Criteria
- Strategy
- Method
- Responsible Organization

#### **Executing Stage**

- Schedule verification and validation Events
- Execute verification and validation Procedures
- Record verification and validation results

#### **Defining Stage**

- Define verification and validation Activities
- For each verification and validation Instance included in a verification or validation Activity, define a set of procedure requirements that will result in the verification or validation Strategy to be realized using the selected Method
- Develop verification and validation Procedures

Repeat for each system and system element that is part of the physical architecture

#### **Reporting Stage**

- Prepare a verification and validation Execution
   Record for each verification and validation
   Activity
- Prepare a verification and validation Approval Package
- Provide the verification and validation Approval Package to the Approving Authority

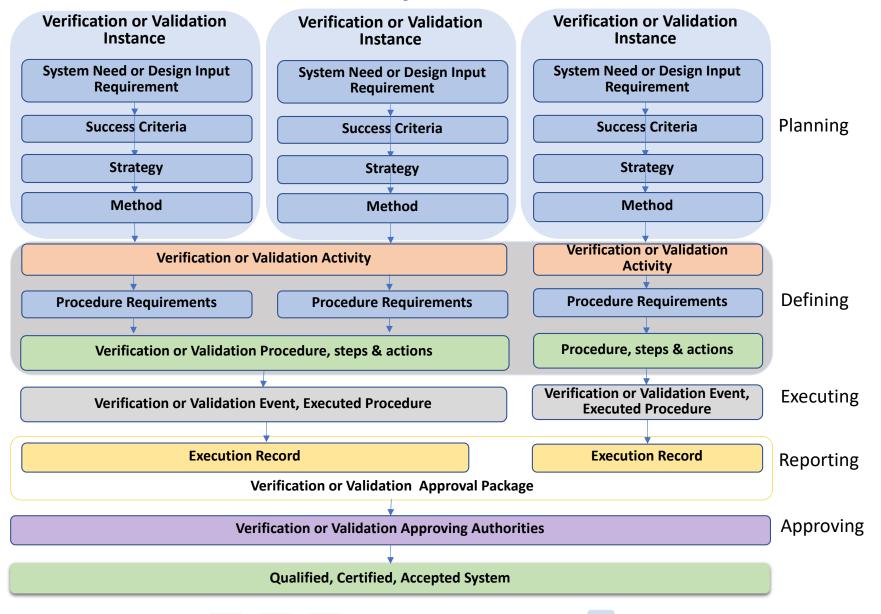
#### **Approval Stage**

 Gain Approval (Qualification, Certification, Acceptance)
 from the Approving Authority

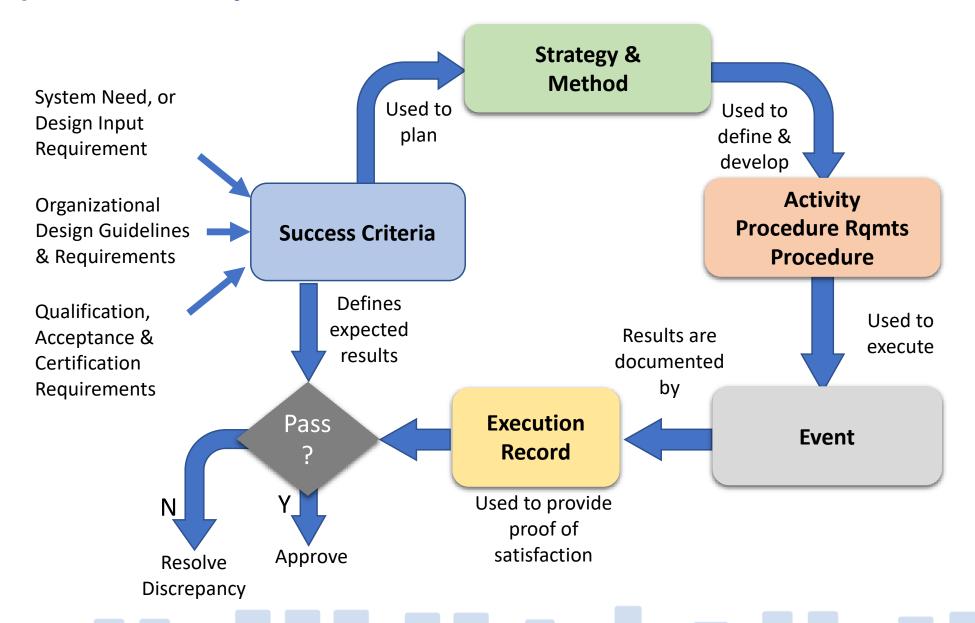
System that is: verified to meet the design input requirements and validated to meet the integrated set of needs

# System Verification & System Validation Artifacts





# Sequence of System Verification & Validation Activities



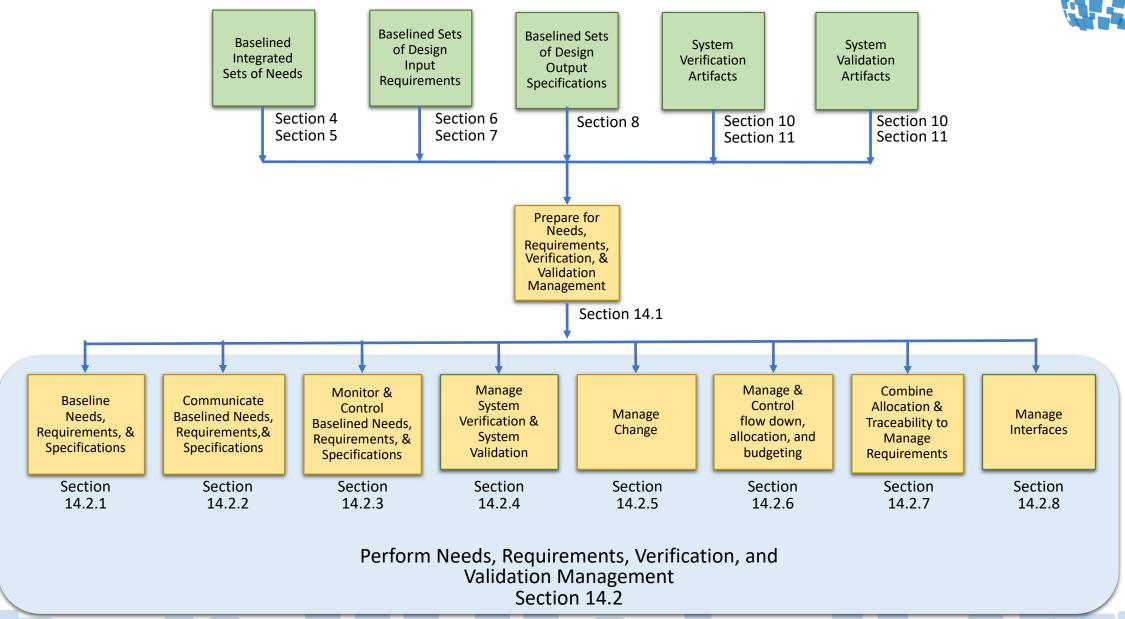
# **Table of Contents**



SECTION	12: THE USE OF OTS SYSTEM ELEMENTS	370
SECTION	13: SUPPLIER DEVELOPED SOI	375
13.1	CUSTOMER/SUPPLIER RELATIONSHIPS	375
13.2	CUSTOMER/SUPPLIER VERIFICATION VERSUS VALIDATION CONSIDERATIONS	381
13.3	Addressing the Evolutionary Nature of Interface Definitions	385
SECTION	14: NEEDS, REQUIREMENTS, VERIFICATION, AND VALIDATION MANAGEMENT	386
14.1	PREPARE FOR NEEDS, REQUIREMENTS, VERIFICATION, AND VALIDATION MANAGEMENT	387
14	1.1 Project Management and Systems Engineering Plans	388
14	1.2 Needs and Requirements Definition and Management Plan	389
14.	1.3 Verification and System Validation Management Plans	390
14	1.4 Configuration Management Plan	391
14.2	PERFORM NEEDS, REQUIREMENTS, VERIFICATION, AND VALIDATION MANAGEMENT	392
14.	2.1 Baseline Needs, Requirements, and Specifications	393
14.	2.2 Communicate Baselined Needs, Requirements, and Specifications	394
14.	2.3 Monitoring and Controlling the Baselined Needs, Requirements, and Specifications	395
14.	2.4 Managing System Verification and System Validation	395
14	2.5 Managing Change	397
14	2.6 Manage and Control the Flow Down, Allocation, and Budgeting	404
14.	2.7 Combine Allocation and Traceability to Manage Requirements	405
14		

### Needs, Requirements, Verification, and Validation Management





# **Table of Contents**

SECTION	15: ATTRIBUTES FOR NEEDS AND REQUIREMENTS	413
15.1	ATTRIBUTES TO HELP DEFINE NEEDS AND REQUIREMENT AND THEIR INTENT	414
15.2	ATTRIBUTES ASSOCIATED WITH SYSTEM VERIFICATION AND SYSTEM VALIDATION	v416
15.3	ATTRIBUTES TO HELP MANAGE THE NEEDS AND REQUIREMENTS	417
15.4	ATTRIBUTES TO SHOW APPLICABILITY AND ENABLE REUSE	
15.5	ATTRIBUTES TO AID IN PRODUCT LINE MANAGEMENT	426
15.6	GUIDANCE FOR USING ATTRIBUTES	428
SECTION	16: FEATURES AN SE TOOLSET SHOULD HAVE	431
16.1	CHOOSING AN APPROPRIATE TOOLSET	431
16.2	FEATURES A SYSTEMS ENGINEERING TOOLSET SHOULD HAVE	432
16.3	3.1 Functionality	
16.3		
16.3		
<b>16.</b> 3	3.4 General Considerations	439
APPENDIX	IX A: REFERENCES	440
APPENDIX B: ACRONYMS AND ABBREVIATIONS		443
APPENDIX C: GLOSSARY		446
APPENDIX	IX D: COMMENT FORM	458



# **Questions and Discussion**





www.incose.org/IW2022