

INTRODUCTION

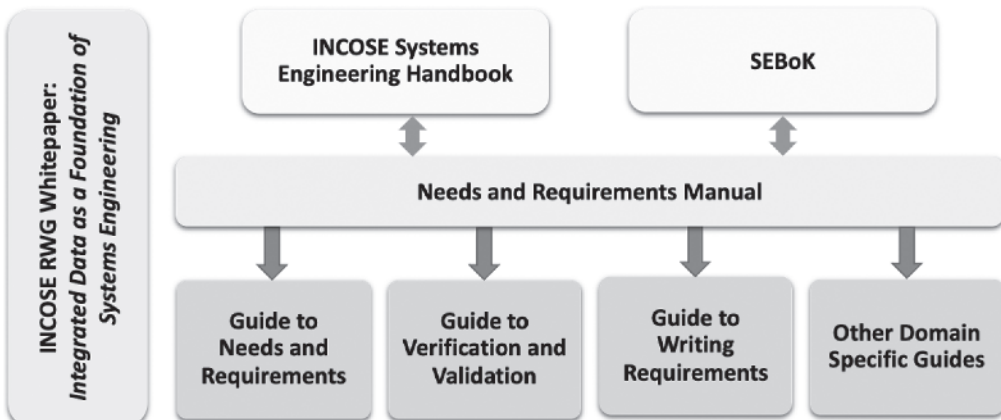
1.1 PURPOSE

This Needs and Requirements Manual (NRM) presents systems engineering (SE) from the perspective of the definition and management across the system lifecycle of needs, requirements, verification, and validation (NRVV). NRVV are common threads that tie together all lifecycle activities and processes.

As presented in this Manual, for acceptance, certification, and qualification, the system or product being developed is verified against design input requirements and validated against its integrated set of needs. To successfully complete system verification and system validation, the needs and requirements of the system as well as the system verification and validation artifacts must be managed throughout the entire system lifecycle. This Manual provides practical guidance on the concepts and activities required to achieve those outcomes.

As shown in Figure 1.1, this Manual supplements and elaborates the INCOSE Systems Engineering Handbook (SE HB) [1] and the Systems Engineering Body of Knowledge (SEBoK) [2], providing more detailed guidance on the “what,” “how,” and “why” concerning NRVV across the system lifecycle. The NRM also addresses ambiguity and inconsistencies in NRVV terminology and ontology.

Figure 1.1 shows this Manual is further elaborated by several supporting guides. The *Guide to Needs and Requirements* (GtNR) [3] and the *Guide to Verification and Validation* (GtVV) [4] focus further on the “what” and “how” of the specific processes being implemented within an organization. The level of detail is similar in content to an organization’s Work Instructions (WIs) or Standard Operating Procedures (SOPs). These guides reference this Manual for specific guidance on the “why” and underlying concepts, maintaining consistency in approach and ontology defined in this Manual.



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FIGURE 1.1 Relationships Between INCOSE Requirements Working Group (RWG) Products and the INCOSE SE HB and SEBoK.

Although this Manual addresses the activities and underlying analysis associated with defining individual and sets of needs and design input requirements, the actual writing of the need and requirement statements is covered in the INCOSE *Guide to Writing Requirements* (GtWR) [5]. The GtWR includes a list of key characteristics of well-formed needs and requirements and sets of needs and requirements, as well as a set of rules that can help achieve those characteristics. Throughout this Manual, when the activities being discussed contribute to a given characteristic defined in the GtWR, a trace to that characteristic is included.

Figure 1.1 also shows that this Manual and the associated guides advocate a data-centric approach to Project Management (PM) and SE as defined in the INCOSE RWG Whitepaper *Integrated Data as a Foundation of Systems Engineering* [6], as discussed in Chapter 3 of this Manual.

1.2 SCOPE

To support PM and SE from an NRVV perspective, this Manual:

- Provides PM and SE practitioners with an understanding of the best practices for effective NRVV definition and management throughout the system lifecycle.
- Helps organizations understand that NRVV are key elements of SE activities.
- Provides guidance to the successful implementation of NRVV activities as part of PM and SE, in any domain.
- Reinforces the idea that adequate definition of lifecycle concepts and a well-formed set of needs is a prerequisite to the definition of a well-formed set of system design input requirements.
- Provides practical, cross-domain guidance to enable organizations to integrate best practices and concepts within their PM and SE processes, activities, WIs, and procedures.
- Provides a clear description of how the terms verification and validation are applied to the artifacts generated across the system lifecycle.
- Describes the importance of planning early for verification and validation activities across the lifecycle and the inclusion of verification and validation artifacts in system models.

- Provides thorough guidance to readers on planning, definition, execution, and reporting of verification and validation activities across the system lifecycle.
- Provides guidance and best practices that will help customers avoid accumulating technical debt and enable projects and suppliers to deliver a winning product.
- Presents a data-centric approach to NRVV definition and management.
- Provides guidance for organization- and enterprise-wide sharing of data and information associated with developing and managing an integrated set of needs, the resulting design input requirements, and design output specifications, as well as verification and validation artifacts throughout the system lifecycle.

1.3 AUDIENCE

This Manual is intended for those whose role is to perform NRVV activities throughout the system lifecycle. This includes those who *verify* that the design and realized System of Interest (SOI) meet the requirements and those who *validate* that the requirements, design, and realized SOI meet the needs in the intended operational environment when used by the intended users and mitigate risk of any misuse of the SOI and losses because of misuse.

This Manual is addressed to practitioners of all levels of experience. Someone new to PM and SE should find the specific guidance useful, and those more experienced should be able to find new insights concerning NRVV across all stages of the system lifecycle, which is often absent from other texts, guides, or standards, particularly in terms of a data-centric perspective.

Major user groups who will benefit from the use of this Manual include systems engineers, requirements engineers, business analysts, product developers, system architects, configuration managers, designers, testers, verifiers, validators, manufacturers, coders, operators, users, disposers, course developers, trainers, tool vendors, project managers, acquisition personnel, lawyers, regulators, and standards organizations. Specific use cases for various classes of readers are shown in Table 1.1.

1.4 APPROACH

While this Manual addresses the specific application of the activities and concepts associated with NRVV, the specifics of “how” this information is applied are not prescribed. For example, while the use of models and a data-centric approach is advocated, the specifics concerning how to implement these concepts within the project’s toolset are not addressed; while the use of Requirement Management Tools (RMTs) is advocated, the specifics concerning any particular RMT are not discussed. In this regard, this Manual is structured to enable other INCOSE Working Groups (WGs) and tool vendors to develop domain or tool-specific guides that tailor these contents to best fit the needs of the organization.

There are many use cases for how organizations practice SE to develop systems and products. This Manual presents a generic set of concepts and activities that can be applied. It is not intended that organizations adopt all the activities presented, but rather use the best practices presented to tailor their product development activities and processes appropriate to their domain, product line, workforce, and culture in such a way that provides the most value. For additional guidance concerning tailoring, refer to Chapter 4 of the INCOSE SE HB [1].

TABLE 1.1 NRVV Use Cases.

Reader	Use Cases
Novice practitioners: those new to SE and NRVV	• Learn and understand NRVV terminology, concepts, and best practices • Access a structured, unambiguous, and comprehensive source of information and knowledge to help learn NRVV from a data-centric perspective • Learn a consistent and unambiguous ontology (meta-model) for NRVV
Seasoned practitioners: those experienced in SE and NRVV but not from a data-centric perspective	• Gain more in-depth understanding of NRVV from a data-centric perspective • Reinforce, refresh, build upon, and renew their NRVV knowledge • Tailor the concepts in the NRM to their organization’s product line, processes, and culture • Adopt the NRVV best practices presented in this Manual • Use this Manual to help mentor novice practitioners in the realm of NRVV
Course developers/educators/trainers: individuals or organizations that specialize in training practitioners and other stakeholders in NRVV processes and tools	• Use a structured, unambiguous, and comprehensive source of information and knowledge to help teach NRVV from a data-centric perspective • Suggest relevant NRVV topics to trainers for their course content • Present a consistent and unambiguous ontology for NRVV. • Lead SE curricula development and revision inside their own organizations based on best practices and knowledge presented in this Manual
Tool vendors: organizations that provide applications that enable the data-centric practice of SE	• Implement recommended features in a toolset to enable practitioners to develop and manage NRVV across the system lifecycle from a data-centric perspective • Align their PM and SE toolset products with a comprehensive set of NRVV activities and artifacts and underlying data and information • Apply Artificial Intelligence (AI) as a “digital assistant,” helpful in the performance of the activities defined in this Manual
Project managers: those who manage product development projects	• Understand overall product development lifecycle processes from the perspective of SE and NRVV • Understand what a data-centric practice of SE means and its advantages • Understand the value and importance of SE and NRVV activities to project success—and the importance of budgeting for and scheduling such activities • Understand how measures and metrics managed within the SE toolset can help better manage product development projects • Provide an accurate and comprehensive SE and NRVV reference, for both training and practitioner use • Provide more accurate cost and schedule estimates for complex systems engineering projects • Suggest cost and schedule savings to complex systems engineering projects, even without an engineering background

TABLE 1.1 (Continued)

Reader	Use Cases
Non-SE stakeholders: those involved in non-SE project activities	• Understand basic terminologies, scope, best practices, artifacts, and value associated with SE and NRVV from a data-centric perspective • Understand how various NRVV activities and artifacts relate to other SE and PM activities and artifacts • Understand NRVV activities and the various opportunities for cross-functional collaboration between non-SE stakeholders and SE practitioners
Customers: those who request a work product or outsource the development of an SOI to a supplier.	• Understand overall product development lifecycle processes from the perspective of SE and NRVV activities. • Understand the role that both the customer and supplier have in these activities.
Suppliers: those who supply an SOI to a customer.	• Understand the importance of clearly defining in the supplier Statement of Work (SOW), Statement of Objectives (SOO), Performance Work Statement (PWS), or Supplier Agreement (SA) processes and deliverables and the relationships of the customer/supplier roles and responsibilities concerning the development, manufacturing, coding, verification, and validation of an SOI. • Understand the relationship between needs and a customer's strategic objectives driving them. • Understand why the integrated system must be managed across all lifecycle activities. • Understand why an integrated set of needs must be defined, against which the integrated system will be validated prior to defining the set of design input requirements. • Understand the value of providing suppliers with the underlying analysis and resulting data and information used to define the integrated set of needs and set of design input requirements.

Note: The end item being developed can be referred to as either a system or a product. Either term implies the integrated system, which comprises subsystems and lower-level system elements (assemblies, sub-assemblies, and components) that are defined within the system architecture. An SOI is a specific entity (system, subsystem, or system element) that is to be defined, developed, verified, validated, and delivered to either internal or external customers and then used, sustained, and retired. The concepts discussed here apply to any SOI, no matter where it exists in the physical architecture, so the term SOI will be used to stand for both systems and products.

1.5 MAPPING OF NRVV ACROSS STANDARDS

Various PM and SE organizations and standards may name and group the NRVV activities discussed in this Manual differently, combining several of these activities and assigning various names to the resulting technical processes as shown in Table 1.2.

TABLE 1.2 NRVV Activities as Addressed by Various Organizations and Standards.

	PMI®	SEI®/CMMI®	ISO/IEC/IEEE 15288/29148	INCOSE SE HB	NASA NPR 7123 & SE HB
Requirements Development	X	X			
Requirements Management	X	X			X
Business or Mission Analysis Process			X	X	
Stakeholder Needs and Requirements Definition			X	X	
Systems Requirements Definition			X	X	
Stakeholder Expectations Definition					X
Technical requirements definition					X
System verification	X	X	X	X	X
System validation	X	X	X	X	X

The Project Management Institute (PMI®) and Carnegie Mellon’s Software Engineering Institute (SEI®) Capability Maturity Model Integrated (CMMI®) separate requirements development and management into two separate processes, “*Requirements Development*” and “*Requirements Management*.” Verification and validation of the lifecycle concepts and needs and of the resulting design input requirements are divided between the two main processes. Lifecycle concepts analysis and maturation and needs definition are included as part of *Requirements Development*, and management of lifecycle concepts and needs is included as part of *Requirements Management*.

ISO/IEC/IEEE 15288 [7] defines needs and requirements in terms of organizational levels: organizational (enterprise), strategic, operational, system, and system elements. Lifecycle concepts, needs, and requirements (CNR) are defined for each level at a level of abstraction appropriate to that level. The INCOSE SE HB divides requirement development and management into three technical process areas in accordance with ISO/IEC/IEEE 15288: *Business or Mission Analysis Process* for lifecycle CNR at the strategic level, *Stakeholder Needs and Requirements Definition Process* for lifecycle CNR at the operational level, and *Systems Requirements Definition Process* for lifecycle CNR at the system level and below. Chapter 2 of this Manual provides a more detailed discussion of levels of lifecycle CNR.

In the context of the CMMI, *Requirement Development* process, ISO/IEC/IEEE 15288, ISO/IEC/IEEE 29148 [8], and INCOSE SE HB [1] separate *Requirements Development* activities into the above mentioned three areas such that *Business or Mission Analysis Process* and *Stakeholder Needs and Requirements Process* correspond to the development of stakeholder needs, and *System Requirements Definition Process* corresponds to the development of the system-level requirements.

Within ISO/IEC/IEEE 15288, ISO/IEC/ IEEE 29148, and the INCOSE SE HB technical processes, system-level lifecycle CNR are combined into one process area: *Systems Requirements Definition*. In addition, in these documents, there is no *separate* needs and requirement management process to address the activities associated with needs and requirements management. Instead, needs and requirements management is included as part of the *Systems Requirements Definition Process* activities, and other technical process.

While including the lifecycle processes contained in ISO/IEC/IEEE 15288, ISO/IEC/IEEE 29148 also includes clause 6.6 concerning requirements management as a distinct activity.

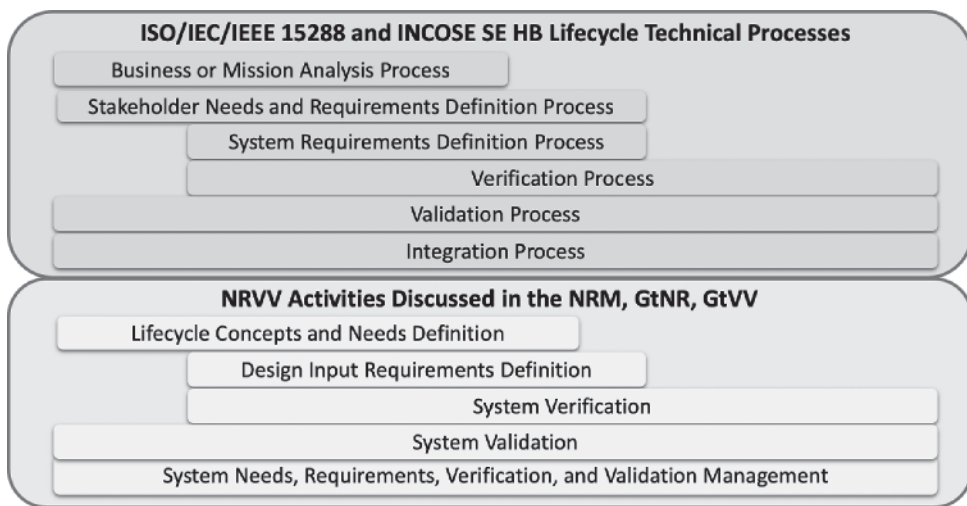
The National Aeronautics and Space Administration (NASA) NASA Procedural Requirements (NPR) 7123.1C, NASA SE Processes and Requirements Document [9], and the companion NASA SE HB NASA/SP-2016-6105 [10] define three process areas that address needs and requirements: *Stakeholder Expectations Definition*, *Technical Requirements Definition*, and *Requirement Management*. The *Stakeholder Expectations Definition* and *Requirements Definition* processes are similar to those defined in ISO/IEC/IEEE 15288, ISO/IEC/IEEE 29148, and INCOSE SE HB; however, NASA includes a separate crosscutting *Requirement Management* process.

Another difference between the NASA SE HB and the INCOSE SE HB is that the NASA SE HB *Stakeholder Expectations Definition Process* does not use the terms stakeholder needs and stakeholder requirements. However, the form of communicating stakeholder expectations is not specifically stated, implying that the stakeholder expectations are communicated via Operations Concept (OpsCon) and Concept of Operations (ConOps) documents. *See Chapter 4 for a more detailed discussion concerning OpsCon versus ConOps.*

All organizations include distinct verification and validation processes; however, the organizational element within an organization responsible for these activities tends to vary. PMI/CMMI places verification and validation activities as part of Quality Management (QM), while INCOSE and NASA place verification and validation activities as part of SE.

1.6 THE FIVE NRVV ACTIVITY AREAS DISCUSSED IN THIS MANUAL

As shown in Figure 1.2, the five NRVV activity areas defined below trace to, and are an elaboration of, the *Business or Mission Analysis*, *Stakeholder Needs and Requirements Definition*, *System Requirements Definition*, *Verification*, and *Validation* technical process activities defined in ISO/IEC/IEEE 15288 and INCOSE SE HB. *Note: These activity areas are highly integrated*



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FIGURE 1.2 Relationship of INCOSE SE HB Technical Processes and NRVV Activities Discussed in this Manual.

with and dependent on the other technical processes defined in ISO/IEC/IEEE 15288 and INCOSE SE HB, including the Architectural Definition Process, Design Definition Process, and Integration Process as well as the crosscutting Interface Management and the technical management processes. Because of the dependencies, the activities and processes shown in Figure 1.2, are best performed concurrently rather than serially.

The focus of this Manual is on the NRVV activities required for an SOI to be developed, managed, delivered, used, sustained, and retired. This Manual divides these activities into the following five activity areas:

- *Lifecycle Concepts and Needs Definition:* The focus is on defining a feasible set of lifecycle concepts and a well-formed integrated set of needs that will result in an SOI that will meet the defined problem or opportunity; mission, goals, and objectives (MGOs); measures; needs; and requirements defined at the operational and strategic levels of the organization as well as by an external customer. *Lifecycle Concepts and Needs Definition activities are discussed in detail in Chapters 4 and 5.*
- *Design Input Requirements Definition:* The focus is on transforming the baselined integrated set of needs for an SOI into well-formed design input requirements expressed as “shall” statements that are inputs for defining the SOI physical architecture, flowing requirements down the architecture, and realization of the SOI via a design solution. The design input requirements address what the system, subsystem, or system element must do to satisfy their integrated set of needs from which they were transformed without stating how they are to be implemented (design outputs). *Design Input Requirements Definition is discussed in detail in Chapters 6 and 7.*
- *System Verification.* The focus is on planning for system verification, executing those plans, recording the results, and reporting the results to an Approval Authority. *System Verification is discussed in detail in Chapters 10 and 11.*
- *System Validation.* The focus is on planning for system validation, executing those plans, recording the results, and reporting the results to an Approval Authority. *System Validation is discussed in detail in Chapters 10 and 11.*
- *Needs, Requirements, Verification, and Validation Management.* The focus is on managing the sets of needs and the sets of design input requirements, including managing the needs and requirement definition activities, managing the flow down (allocation and budgeting) of requirements from one level to another, validating bidirectional traceability, and managing the design and system verification and validation artifacts. *Needs, Requirements, Verification, and Validation Management are discussed in detail in Chapter 14.*

1.7 NEEDS AND REQUIREMENTS MANUAL ORGANIZATION

This Manual is organized as follows:

- Chapter 1 introduces the Manual.
- Chapter 2 provides definitions and discusses key concepts and ontology used throughout the Manual.
- Chapter 3 discusses the concept of Information-based Needs and Requirements Definition and Management (I-NRDM).
- Chapter 4 discusses Lifecycle Concepts and Needs Definition activities.
- Chapter 5 discusses Need Verification and Validation activities.

- Chapter 6 discusses Design Input Requirements Definition activities.
- Chapter 7 discusses Design Input Requirement Verification and Validation activities.
- Chapter 8 discusses Design Verification and Design Validation activities.
- Chapter 9 discusses Production Verification activities.
- Chapter 10 discusses system verification and validation common principles.
- Chapter 11 discusses System Verification and Validation activities.
- Chapter 12 discusses the use of Off-the-Shelf (OTS) system elements.
- Chapter 13 discusses design and system verification and design and system validation considerations when using supplier-developed system elements.
- Chapter 14 discusses Needs, Requirements, Verification, and Validation Management activities.
- Chapter 15 discusses the use of attributes.
- Chapter 16 discusses the desirable features of an SE toolset.
- Appendix A lists references for sources of information in this Manual.
- Appendix B lists acronyms and abbreviations used in this Manual.
- Appendix C provides a glossary defining key terms used in this Manual.
- Appendix D provides a comment form and address to which comments on this Manual can be sent.

