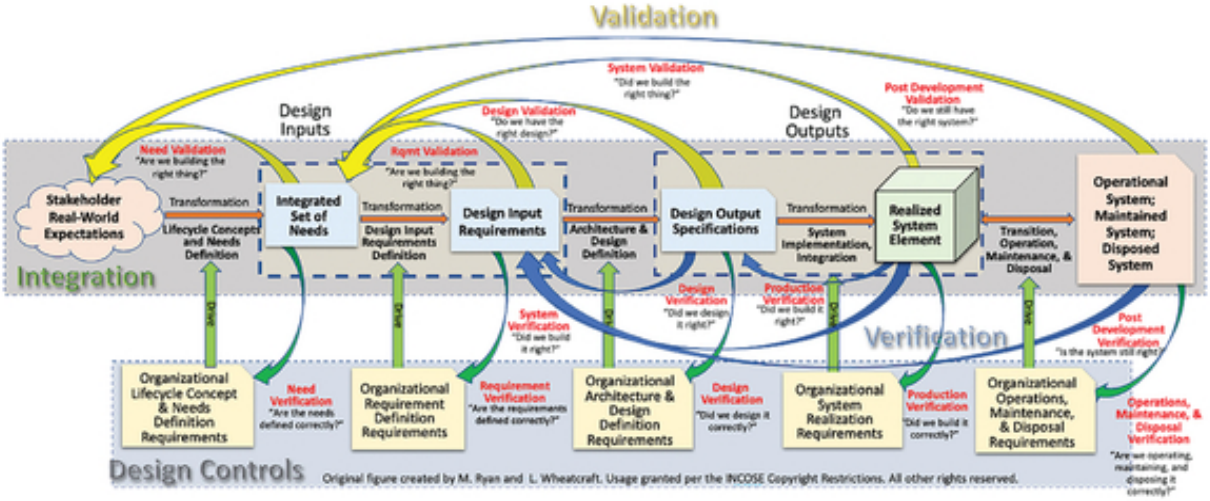
INCOSE

# Needs and Requirements Manual

## Needs, Requirements, Verification, Validation Across the Lifecycle





Written by

Louis S. Wheatcraft • Michael J. Ryan

Tami Edner Katz



WILEY

# INCOSE NEEDS AND REQUIREMENTS MANUAL

# INCOSE NEEDS AND REQUIREMENTS MANUAL

## NEEDS, REQUIREMENTS, VERIFICATION, VALIDATION ACROSS THE LIFECYCLE

**INCOSE-TP-2021-002-01**
**2024**

**Prepared by:**

**Requirements Working Group**
**International Council on Systems Engineering (INCOSE)**
**7670 Opportunity Road, Suite 220**
**San Diego, California 92111-2222 USA**

**Written by:**

**Louis S. Wheatcraft**
**Michael J. Ryan**
**Tami Edner Katz**

WILEY

Copyright © 2025 by John Wiley & Sons, Inc. All rights reserved, including rights for text and data mining and training of artificial intelligence technologies or similar technologies.

Published by John Wiley & Sons, Inc., Hoboken, New Jersey.
Published simultaneously in Canada.

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning, or otherwise, except as permitted under Section 107 or 108 of the 1976 United States Copyright Act, without either the prior written permission of the Publisher, or authorization through payment of the appropriate per-copy fee to the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, (978) 750-8400, fax (978) 750-4470, or on the web at www.copyright.com. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at http://www.wiley.com/go/permission.

Trademarks: Wiley and the Wiley logo are trademarks or registered trademarks of John Wiley & Sons, Inc. and/or its affiliates in the United States and other countries and may not be used without written permission. All other trademarks are the property of their respective owners. John Wiley & Sons, Inc. is not associated with any product or vendor mentioned in this book.

Limit of Liability/Disclaimer of Warranty: While the publisher and author have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives or written sales materials. The advice and strategies contained herein may not be suitable for your situation. You should consult with a professional where appropriate. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages.

For general information on our other products and services or for technical support, please contact our Customer Care Department within the United States at (800) 762-2974, outside the United States at (317) 572-3993 or fax (317) 572-4002.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic formats. For more information about Wiley products, visit our web site at www.wiley.com.

***Library of Congress Cataloging-in-Publication Data Applied for:***

Hardback ISBN: 9781394152742

Cover Design: Wiley
Cover Image: Courtesy of Michael J. Ryan and Louis S. Wheatcraft

Set in 10/12pt TimesLTStd by Straive, Chennai, India

# CONTENTS

**INCOSE Notices** xv

**Preface** xvi

**Authors** xvii

**Major Contributors** xviii

**Reviewers** xix

**Revision History** xx

**List of Figures** xxi

**List of Tables** xxiv

**1 Introduction** 1

1.1 Purpose 1
1.2 Scope 2
1.3 Audience 3
1.4 Approach 3
1.5 Mapping of NRVV Across Standards 5
1.6 The Five NRVV Activity Areas Discussed in this Manual 7
1.7 Needs and Requirements Manual Organization 8

**2 Definitions and Concepts** 11

2.1 Ontology used in this Manual 11
2.1.1 Stakeholder Expectations, Needs, and Requirements 12
2.1.2 Needs Versus Requirements 12
2.1.2.1 Integrated Set of Needs 12
2.1.2.2 Design Input Requirements 13
2.1.2.3 Different Perspectives Communicated by Needs and Requirements 14

2.1.3 Stakeholder Requirements Versus System Requirements in the Context of System Verification and System Validation 14
2.1.4 Requirements Versus Specifications and Documents Versus Specifications 15
2.1.4.1 Design Inputs Versus Outputs 15
2.1.4.2 Documents Versus Data-Centric Sets 16
2.2 Definitions 16
2.2.1 Entities 17
2.2.2 Lifecycle Concepts 18
2.2.3 Needs 18
2.2.4 Requirements 18
2.2.5 Attributes 19
2.2.6 Needs and Requirements Expressions 19
2.2.7 Sets of Needs and Sets of Requirements 20
2.3 Basic Concepts 20
2.3.1 Needs, Requirements, and the Entity to Which They Apply 20
2.3.2 Levels of Lifecycle Concepts, Needs, and Requirements 22
2.3.2.1 Levels in the Context of an Organization 22
2.3.2.2 Use of Systems Thinking—The SOI in Context of the Macrosystem 28
2.3.2.3 Portfolio Management Within the Operational Level 29
2.3.2.4 SOI Customer/Supplier Relationship Considerations 30
2.3.2.5 Levels of Architecture—a Hierarchical View 32
2.3.2.6 Levels of Architecture—a Holistic View 33
2.3.2.7 Using Both the Hierarchical and Holistic Architecture Views 36
2.3.3 Verification and Validation in Context 37
2.3.3.1 Distinctions Between the Concepts of Verification and Validation 39
2.3.3.2 System Verification and Validation After Product Release 44
2.3.4 Integration, Verification, and Validation and the SE Vee Model 45
2.3.4.1 Concurrent Integration, Verification, and Validation 46
2.3.4.2 System Verification Versus Requirement Verification 47
2.3.4.3 System Verification Based on Lower-Level Verifications 47
2.3.4.4 Verification and Validation in Context 48
2.3.4.5 The Intent of System Verification and System Validation 48
2.3.4.6 Reducing Risk by Addressing System Verification and Validation Early in the Lifecycle 50
2.3.5 Project and Systems Engineering Management Concepts 51
2.3.5.1 Importance of an Integrated, Multidiscipline, Collaborative Project Team 51
2.3.5.2 Importance of Effective Communications 53
2.3.5.3 Avoiding Technical Debt 55
2.3.5.4 Greenfield Versus Brownfield Systems 57
2.3.6 Overview of System Development Activities Covered in This Manual 58

**3 Information-Based Needs and Requirement Development and Management 63**

3.1 Information-Based Needs and Requirements Definition and Management 64
3.1.1 Key Characteristics of the I-NRDM Approach 66
3.1.1.1 Implementing Development Lifecycle Phase Activities Concurrently Rather Than Serially 66

3.1.1.2 Using a Holistic Versus A Silo-based Organization Structure 68
3.1.1.3 Focusing on the Integrated System Optimization Versus Subsystem Optimization 68
3.1.1.4 Using SE Tools Having the Capability to Share Data and Information 68
3.1.1.5 Establishing Well-Formed Sets of Needs and Design Input Requirements with an Underlying Data and Information Model 69
3.1.1.6 Defining a Project Ontology and Master Database Schema at the Beginning of the Project 69
3.1.1.7 Capturing Dependencies and Relationships 69
3.1.1.8 Using Tools That Allow Requirement Data to Be Referenced and Modeled 69
3.1.1.9 Using RMT and Modeling Tools That Help Ensure Need and Requirement Statements are Well-Formed 69
3.1.1.10 PM Work Products are Developed Concurrently with the Development of the SE Artifacts 70
3.1.2 Implementing the I-NRDM Approach 70
3.2 Expression of Text-Based Needs and Requirements within RMTS Versus Models and Diagrams 70
3.2.1 Expression of Text-based Needs and Requirements Within RMTs 71
3.2.1.1 Communication and Comprehension 71
3.2.1.2 Power of Expression 71
3.2.1.3 Managing Sets of Needs and Requirements 72
3.2.1.4 Use of Attributes 73
3.2.1.5 The Need for a Formal, Binding Agreement 73
3.2.1.6 Necessary for Acceptance, Qualification, Certification, and Approval for Use 73
3.2.2 Expressing Needs and Requirements Within Models and Diagrams 74
3.2.2.1 Analysis from Which Needs and Requirements are Derived 74
3.2.2.2 Completeness 74
3.2.2.3 Consistency 75
3.2.2.4 Identify and Manage Interdependencies 75
3.2.2.5 Support Simulations 75
3.2.2.6 Comprehensive System View 75

**4 Lifecycle Concepts and Needs Definition 77**

4.1 Introduction 77
4.1.1 Necessary for Acceptance 78
4.1.2 Lifecycle Concepts and Needs Definition Activities 78
4.1.3 Change Across the Lifecycle 80
4.1.4 Benefits of Lifecycle Concepts and Needs Definition Activities 81
4.2 Prepare for Lifecycle Concepts and Needs Definition 81
4.3 Define Inputs to Lifecycle Concepts Analysis and Maturation 82
4.3.1 Define the Problem, Threat, or Opportunity 83
4.3.2 Define Mission, Goals, Objectives (MGOs), and Measures 84
4.3.2.1 Mission Statement 85
4.3.2.2 Goals 86
4.3.2.3 Objectives 87

4.3.2.4 Measures 88
4.3.2.5 Special Considerations 89
4.3.2.6 Recording and Managing the MGOs and Measures 90
4.3.3 Identify External and Internal Stakeholders 90
4.3.3.1 Stakeholder Perspectives 93
4.3.3.2 Creating a Stakeholder Register 96
4.3.3.3 Stakeholder Considerations 96
4.3.4 Elicit Stakeholder Needs 99
4.3.4.1 Plan for Elicitation 99
4.3.4.2 Information to Be Elicited from Stakeholders 99
4.3.4.3 Use of Checklists 104
4.3.4.4 Elicitation Techniques and Methods 105
4.3.5 Document Elicitation Outcomes 106
4.3.5.1 Considerations Concerning the Elicitation Outcomes 107
4.3.5.2 Elicitation Completeness Checklist 110
4.3.6 Identify Drivers and Constraints 110
4.3.6.1 Standards and Regulations 111
4.3.6.2 Technology Maturity 116
4.3.6.3 Existing Systems 116
4.3.6.4 Higher-Level Lifecycle CNR 119
4.3.6.5 Budget and Schedule 119
4.3.6.6 Operational Environment 120
4.3.7 Identify, Assess, and Handle Risk 122
4.3.7.1 Types of Risk 122
4.3.7.2 Risk Assessment and Handling 127
4.4 Capture Preliminary Integrated Set of Lifecycle Concepts 130
4.4.1 Perspectives 132
4.4.1.1 Business/Project Management Perspective 133
4.4.1.2 Operational Perspective 133
4.4.1.3 System Perspective 133
4.4.2 Concept of Operations versus Operations Concept 134
4.4.3 Obtain Stakeholder Agreement 134
4.5 Lifecycle Concepts Analysis and Maturation 135
4.5.1 Feasibility 136
4.5.2 Design as Part of the Lifecycle Concepts Analysis and Maturation Activities 137
4.5.3 Use of Diagrams and Models for Analysis 138
4.5.3.1 Types of Diagrams and Models 139
4.5.3.2 Considerations When Developing Diagrams and Models 140
4.5.4 Examples of Functional/Activity Analysis Using Diagrams and Models 141
4.5.4.1 Fundamental System Model 141
4.5.4.2 Functional/Activity Flow Block Diagram 143
4.5.4.3 System Architecture Diagram 144
4.5.5 Levels of Detail and Abstraction 145
4.5.6 Completeness of the Lifecycle Concepts 147
4.5.7 Completeness, Correctness, Consistency, and Feasibility Considerations for SOIs Being Developed to Customer-Supplied System Requirements 149
4.5.8 Risk Assessment 150
4.5.9 Security 152

4.5.10 Human Systems Integration and Human Systems Engineering 152
4.5.11 Systems of Systems (SoS) 153
4.5.12 Standards and Regulations Compliance 153
4.5.13 Iteration to Mature Lifecycle Concepts 154
4.5.13.1 Model Development, Analysis, and Maturation 155
4.5.13.2 Trade Space – Define Candidate Physical Architectures 156
4.5.13.3 Physical Architecture Selection and Analysis 158
4.5.13.4 Zeroing in on a Feasible Architecture and Design 159
4.5.14 Activities Concurrent with Lifecycle Concepts Analysis and Maturation 160
4.6 Define and Record the Integrated Set of Needs 162
4.6.1 People and Process Needs 162
4.6.2 Needs and Requirements from Standards and Regulations 163
4.6.3 Define the Integrated Set of Needs 164
4.6.3.1 The Form of Need Statements 164
4.6.3.2 Including Goals Within the Integrated Set of Needs 165
4.6.3.3 Use of Attributes to Define and Manage Needs 165
4.6.3.4 Organizing the Integrated Set of Needs 166
4.6.4 Record the Integrated Set of Needs 170
4.6.4.1 Managing Unknowns 170
4.6.4.2 Appropriate to Level 171
4.6.4.3 Completeness of the Integrated Set of Needs 172
4.6.4.4 Needs Feasibility and Risk 173
4.7 Plan for System Validation 176
4.8 Baseline and Manage Lifecycle Concepts and Needs Definition Outputs 177

**5 Needs Verification and Validation 179**

5.1 Needs Verification 180
5.1.1 Prepare for Needs Verification 181
5.1.2 Perform Needs Verification 182
5.2 Needs Validation 184
5.2.1 Prepare for Needs Validation 184
5.2.2 Perform Needs Validation 185
5.3 Manage Needs Verification and Validation Results 186
5.4 Use of Attributes to Manage Needs Verification and Validation 187

**6 Design Input Requirements Definition 189**

6.1 Prepare for Design Input Requirements Definition 190
6.2 Perform Design Input Requirements Definition 191
6.2.1 Transforming Needs into Design Input Requirements 193
6.2.1.1 Organizing the Sets of Design Input Requirements 195
6.2.1.2 Considerations for Each Category of Requirement 196
6.2.1.3 Guidelines When Formulating Design Input Requirements 205
6.2.2 Establish Traceability 214
6.2.2.1 Traceability Defined 214
6.2.2.2 Using Traceability to Show Compliance with Standards and Regulations 216
6.2.2.3 Managing Traceability Within a Project's Toolset 217

6.2.2.4 Parent/Child Traceability 218
6.2.2.5 Using Trace Matrices 219
6.2.2.6 Establishing Traceability Among Dependent Peer Requirements 219
6.2.2.7 Guidelines for Recording and Managing Traceability 221
6.2.2.8 Use of Traceability to Manage Requirements 222
6.2.2.9 Requirement Relationships Within Models 222
6.2.3 Defining Interactions and Recording Interface Requirements 223
6.2.3.1 What an Interface "Is" 225
6.2.3.2 What an Interface "Is Not" 226
6.2.3.3 Step 1: Identify the Interface Boundaries 227
6.2.3.4 Step 2: Define the Interactions Across the Interface Boundary 230
6.2.3.5 Step 3: Write the Interface Requirements 236
6.2.3.6 Using RMTs to Manage Interfaces 240
6.2.3.7 Common Interface Requirement Defects and Issues 241
6.2.3.8 Interface Requirements Audit 242
6.2.4 Use of Attributes to Develop and Manage Design Input Requirements 245
6.2.4.1 Inheritance 245
6.2.5 Plan for System Verification 245
6.2.6 Finalize Design Input Requirements Definition 246
6.2.6.1 Record the Design Input Requirements 246
6.2.6.2 Completeness, Correctness, and Consistency 247
6.2.6.3 Requirements Feasibility and Risk 248
6.3 Baseline and Manage Design Input Requirements 252
6.4 Architectural Levels, Flow Down, Allocation, and Budgeting 257
6.4.1 Moving Between Levels of the Architecture 258
6.4.2 Product Breakdown Structure and Document Tree 258
6.4.3 Allocation—Flow Down of Requirements 261
6.4.3.1 Software-Intensive System Architecture 263
6.4.3.2 Allocation Matrix 266
6.4.4 Defining Child Requirements That Meet the Intent of the Allocated Parents 268
6.4.5 Budgeting of Performance, Resource, and Quality Requirements 269
6.4.5.1 Allocations and Budgets Across Interface Boundaries 271
6.4.6 Budget Management: The Use of Margins 272
6.4.7 The SE Vee Model and Moving Between Levels 273
6.4.8 Combining Traceability and Allocation to Manage Requirements 273
6.5 Summary of Design Input Requirements Definition 275

**7 Requirements Verification and Validation 277**

7.1 Requirements Verification 278
7.1.1 Prepare for Requirements Verification 279
7.1.2 Perform Requirements Verification 280
7.2 Requirements Validation 283
7.2.1 Prepare for Requirements Validation 283
7.2.2 Perform Requirements Validation 284
7.3 Manage Requirements Verification and Validation Results 286
7.4 Use of Attributes to Manage Requirements Verification and Validation 286

**8 Design Verification and Design Validation 289**

8.1 Design Definition Process Overview 290
8.2 Early System Verification and Validation 293
8.2.1 Modeling and Simulation Challenges 295
8.3 Updating System Verification and Validation Artifacts 295
8.4 Design Verification 296
8.4.1 Prepare for Design Verification 297
8.4.2 Perform Design Verification 298
8.5 Design Validation 299
8.5.1 Prepare for Design Validation 300
8.5.2 Perform Design Validation 301
8.6 Manage Design Verification and Validation Results 302
8.7 Use of Attributes to Manage Design Verification and Design Validation 303

**9 Production Verification 305**

9.1 Production Verification Defined 305
9.2 Scalability, Repeatability, and Yield 306
9.3 Production Verification Versus System Verification 307
9.4 Verification and Validation of the Manufacturing System 308
9.5 Special Considerations 308
9.6 Production Verification 310

**10 System Verification and Validation Common Principles 311**

10.1 Planning Stage 315
10.1.1 Define the System Verification and Validation Success Criteria 316
10.1.1.1 Formulating the Success Criteria Statement 316
10.1.1.2 Considerations for Defining Success Criteria 319
10.1.2 Determine the Strategy 321
10.1.2.1 Considerations When Determining the Strategy 322
10.1.2.2 System Verification and Validation Using Models 327
10.1.2.3 Strategy Impacts on Design 328
10.1.2.4 Addressing Enabling Systems 328
10.1.2.5 System Integration Approach 329
10.1.2.6 Preliminary versus Final System Verification and Validation 330
10.1.2.7 Embedded Software System Verification and Validation Challenges 332
10.1.3 Select a System Verification or System Validation Method 333
10.1.3.1 Test 333
10.1.3.2 Demonstration 335
10.1.3.3 Inspection or Examination 335
10.1.3.4 Analysis 336
10.1.3.5 Questions Associated with Each Method 341
10.1.3.6 Considerations When Selecting a Method 341
10.1.4 Defining Each Instance 343
10.1.5 System Verification and Validation Matrices 344

10.2 Defining Stage 345
10.2.1 Defining Each *Activity* 346
10.2.2 Gathering the Information Needed to Develop the Procedures 347
10.2.3 Procedure Development 350
10.2.4 Scheduling the System Verification or Validation *Event* 352
10.3 Execution Stage: Performing the *Procedures* 352
10.3.1 Formal System Verification and Validation Processes 353
10.3.2 Discrepancies and Nonconformances 355
10.3.3 Variances, Concessions, Waivers, and Deviations 356
10.3.3.1 Deviations and Waivers 356
10.3.3.2 Variance Management 357
10.4 Reporting Stage: Documenting the Results 358
10.4.1 Chain of Evidence Showing Conformance or Compliance 360
10.4.2 Use of Compliance Matrices 361
10.5 Approval Stage 362
10.6 Use of Attributes to Manage System Verification and Validation Activities 363
10.7 Maintaining the System Verification and Validation Artifacts 364

**11 System Verification and System Validation Processes 367**

11.1 System Verification and Validation per Level 368
11.2 Managing the Project's System Verification and Validation Programs 370
11.3 System Verification Activities 371
11.3.1 Prepare for System Verification—Planning and Defining 371
11.3.2 Perform System Verification Activities—Execution 372
11.3.3 Manage System Verification Results—Reporting and Approval 373
11.4 System Validation Process 374
11.4.1 General Considerations 374
11.4.1.1 Operational and Loss Scenarios and Use and Misuse Cases 374
11.4.1.2 Assessing System Behavior and Emerging Properties 374
11.4.2 Prepare for System Validation—Planning and Defining 375
11.4.3 Perform System Validation Activities—Execution 376
11.4.4 Manage System Validation Results—Recording and Approval 377

**12 The Use of OTS System Elements 379**

**13 Supplier-Developed SOI 385**

13.1 Customer/Supplier Relationships 385
13.1.1 Fixed-Price, Performance-Based Contract 386
13.1.2 Cost-Reimbursement, Performance-Based Contract 387
13.1.3 Cost-Reimbursement, Level of Effort/Term Contract 387
13.1.4 Contracting for Specific Lifecycle Activities 388
13.1.5 Customer Versus Supplier Roles 388
13.1.6 Consequences Resulting from Poorly Written Contracts 389
13.2 Customer/Supplier Verification Versus Validation Considerations 392
13.2.1 Customer Is Responsible for System Validation 392
13.2.2 Supplier Is Responsible for System Validation 393
13.2.3 Addressing the Amount of Supplier-Performed System Validation 393
13.2.4 Expecting System Validation Only 394
13.3 Addressing the Evolutionary Nature of Interface Definitions 395

**14 Needs, Requirements, Verification, and Validation Management 397**

14.1 Prepare for Needs, Requirements, Verification, and Validation Management 399
14.1.1 PM and SE Plans 399
14.1.2 Needs and Requirements Definition and Management Plan 400
14.1.3 System Verification and Validation Management Plans 401
14.1.4 Configuration Management Plan 402
14.2 Perform Needs, Requirements, Verification, and Validation Management 402
14.2.1 Baseline Needs, Requirements, and Specifications 403
14.2.2 Monitoring the Status of Needs, Requirements, and Specifications 405
14.2.3 Controlling the Needs, Requirements, and Specifications 406
14.2.4 Manage Unknowns 406
14.2.5 Manage Change 408
14.2.5.1 Control Needs and Requirements Creep 410
14.2.5.2 Why Needs and Requirements Change 411
14.2.5.3 Change Management Across the Lifecycle 413
14.2.5.4 Change Impact Analysis 414
14.2.6 Manage and Control of Flow Down, Allocation, and Budgeting 416
14.2.7 Combine Allocation and Traceability to Manage Requirements 417
14.2.8 Manage and Control Interfaces 420
14.2.8.1 Best Practices Associated with Managing Interfaces 422
14.2.9 Manage and Control System Verification and Validation Activities 423

**15 Attributes for Needs and Requirements 427**

15.1 Attributes to Help Define Needs and Requirements and Their Intent 428
15.2 Attributes Associated with System Verification and System Validation 430
15.3 Attributes to Help Manage the Needs and Requirements 432
15.4 Attributes to Show Applicability and Enable Reuse 440
15.5 Attributes to Aid in Product Line Management 441
15.6 Guidance for Using Attributes 442

**16 Desirable Features of an SE Toolset 445**

16.1 Choosing an Appropriate Toolset 445
16.2 Desirable Features of an SE Toolset 447
16.2.1 Functionality 448
16.2.2 Tool Attributes 450
16.2.3 Management and Reporting 453
16.2.4 General Considerations 454

**Appendix A: References 455**

**Appendix B: Acronyms and Abbreviations 459**

**Appendix C: Glossary 465**

**Appendix D: Comment Form 487**

**Index 489**

# INCOSE NOTICES

This INCOSE Technical Product was prepared by the International Council on Systems Engineering (INCOSE). It is approved by the INCOSE Technical Operations Leadership for release as an INCOSE Technical Product.

*Author Use.* Authors have full rights to use their contributions in a totally unfettered way with credit to the INCOSE Technical source. Abstraction is permitted with credit to the source.

*INCOSE Use.* Permission to reproduce and use this document or parts thereof by members of INCOSE and to prepare derivative works from this document for INCOSE use is granted, with attribution to INCOSE and the original author(s) where practical, provided this copyright notice is included with all reproductions and derivative works.

*External Use.* This document may not be shared or distributed to any non-INCOSE third party. Requests for permission to reproduce this document in whole or part, or to prepare derivative works of this document for external and commercial use should be addressed to the INCOSE Central Office, 7670 Opportunity Rd., Suite 220, San Diego, CA 92111-2222.

*Electronic Version Use.* Any electronic version of this document is to be used for personal, professional use only and is not to be placed on a non-INCOSE sponsored server for general use.

Any additional use of these materials must have written approval from INCOSE Central.

## ADDITIONAL COPIES/GENERAL INFORMATION

Copies of the *Needs and Requirements Manual*, as well as any other INCOSE document can be obtained from the INCOSE Store. General information on INCOSE, the Requirements Working Group, any other INCOSE working group, or membership may also be obtained from the INCOSE Central Office at:

International Council on Systems Engineering
7670 Opportunity Road, Suite 220
San Diego, California 92111-2222 | USA
E-mail: info@incose.org

Telephone: +1 858-541-1725
Toll Free Phone (US): 800-366-1164
Fax: +1 858-541-1728
Web Site: http://www.incose.org

# PREFACE

This Manual has been prepared and produced by a volunteer group of authors and contributors within the Requirements Working Group (RWG) of the International Council on Systems Engineering (INCOSE).

# AUTHORS

The principal authors of this Manual are:

Lou Wheatcraft, Wheatland Consulting, LLC, USA
Michael Ryan, Capability Associates Pty Ltd, AU
Tami Katz, BAE Systems, USA

# MAJOR CONTRIBUTORS

Those who made a significant contribution to the generation of this Manual are:

Mark Abernathy, Retired, USA

James R. Armstrong, Stevens Institute of Technology, USA

Brian Berenbach, Georgia Institute of Technology, USA

Simone Bergamo, Thales, FR

Ronald S. Carson, PhD, Seattle Pacific University, USA

Jeremy Dick, Retired, UK

Celeste Drewien, Sandia National Labs, USA

James R. van Gaasbeek, Retired, USA

Rick D. Hefner, Caltech, USA

Henrick Mattfolk, Whirlpool, USA

Lamont McAliley, Veracity Engineering, USA

Donald McNally, Woodward, USA

Kevin E. Orr, Eaton Corporation, USA

Michael E. Pafford, Retired, USA

Susan E. Ronning, ADCOMM Engineering LLC, USA

Raymond B. Wolfgang, Sandia National Labs, USA

Gordon Woods, East West Railway Company, UK

Richard Zinni, Harris Corporation, USA

# REVIEWERS

In addition to the authors and contributors, below are the names of those who submitted review comments that were included during the development of this Manual:

Angel Agrawal, Northrop Grumman, USA

Ben Canty, Ball Aerospace and Technologies Corporation, USA

James B. Burns, Johns Hopkins University, USA

Ken Eastman, Ball Aerospace and Technologies Corporation, USA

Raymond Joseph, Odfjell Terminal, Houston, USA

Jenn Molloy, Ball Aerospace and Technologies Corporation, USA

Michele Reed, Shell Products and Technology, USA

Andreas Vollerthun, Dr., KAIAO-Consulting, DE

Beth Wilson, retired, USA

# REVISION HISTORY

| Revision | Revision Date | Change Description and Rationale |
|---|---|---|
| 1.0 | January 2022 | First release |
| 1.1 | May 2022 | Editorial and alignment with other RWG products |
| 2.0 | November 2024 | Major update based on use and comments and alignment with other RWG products. |

# LIST OF FIGURES

1.1. Relationships Between INCOSE Requirements Working Group (RWG) Products and the INCOSE SE HB and SEBoK.
1.2. Relationship of INCOSE SE HB Technical Processes and NRVV Activities Discussed in this Manual.
2.1. Lifecycle Concepts, Integrated Set of Needs, and Design Input Requirements.
2.2. Needs Versus Requirements—Different Perspectives.
2.3. NRVV Activity Relationships to the INCOSE SE HB.
2.4. Entity–Relationship Diagram for Customers, Concepts, Entities, Needs, and Requirements Terms.
2.5. Entity–Relationship Diagram for Needs and Requirements Terms.
2.6. Levels in the Context of an Organization.
2.7. Portfolio of Projects Within the Operational Level.
2.8. Supplier-Developed System.
2.9. Levels of a System—Hierarchical View.
2.10. Interactions and Dependences Internal and External to a System.
2.11. Holistic View of the SOI.
2.12. Verification and Validation Confirm that SE Artifacts Generated During Transformation are Acceptable.
2.13. Needs Verification and Validation.
2.14. Post-production Verification and Validation.
2.15. Lifecycle Processes in Relation to the SE Vee Model.
2.16. Integrated, Multidiscipline, Collaborative Project Team.
2.17. Project Team Organization.
2.18. Communications Model [18, 19].
2.19. System Development Activities Across the Lifecycle.

3.1. I-NRDM + MBD = MBSE.
3.2. Information-based Requirement Development and Management Model.
4.1a. Lifecycle and Needs Definition Activities Part 1.
4.1b. Lifecycle and Needs Definition Activities Part 2.
4.2. *Lifecycle Concepts and Needs Definition* IPO Diagram.
4.3. Example Context Diagram, Boundary Diagram, and External Interface Diagram.
4.4. Inputs to the Lifecycle Concepts Analysis and Maturation Activities.
4.5. Fundamental System Model.
4.6. Functional/Activity Analysis using a SIPOC Diagram.
4.7. Generic Functional Flow Block Diagram or Activity Flow Diagram.
4.8. System Architecture Diagram.
4.9. The Line Between Design Inputs and Design Outputs.
4.10. Input/output Risk Assessment.
4.11. Zeroing in on a Set of Feasible Lifecycle Concepts, Needs, and Architecture.
4.12. Provided Capability Includes People, Process, and Products.
4.13. Sources of the Integrated Set of Needs.
4.14. Needs Feasibility/Risk Bucket.
5.1. Needs Verification and Needs Validation Overview.
5.2. Needs Verification IPO Diagram.
5.3. Needs Validation IPO Diagram.
6.1. Design Input Requirements Definition IPO Diagram.
6.2. Design Input Requirement Definition Activities.
6.3. Function with Multiple Performance Characteristics.
6.4. The “Line” Between Design Inputs and Design Outputs.
6.5. The “Line” Within a System Architecture.
6.6. SOI Requirements “Trace to Source” Includes Parent Requirements and Needs.
6.7. Traceability Relationship Meta-model.
6.8. Example Requirement Parent/Child Trace.
6.9. Complexity is a Function of the Number of Interactions Among System Elements.
6.10. An Interface is a Boundary, Not a Thing.
6.11. Example External Interface, Context, or Boundary Diagram.
6.12. Example System-to-System Interface Diagram.
6.13. New System 2 Interactions with an Existing System 1.
6.14. New System 2 and System 3 Interactions.
6.15. Interactions Between the Spacecraft Bus and the Payload.
6.16. Interface Requirement Traceability.
6.17. Requirements Feasibility/Risk Bucket.
6.18. PBS and Associated Sets of Engineering Artifacts.
6.19. Document Tree Diagram Example for the Lid Installation Robot.

6.20. Flow down of Design Input Requirements via Allocation and Budgeting.
6.21. Requirements At One Level Drive the Requirements at the Next Level.
6.22. Alternate Architecture for Software-Intensive Systems.
6.23. Architecture for a Medical Diagnostic System.
6.24. Allocation and Budgeting Example.
6.25. Allocation and Budgeting Dependencies.
6.26. Allocation and Budgeting Across Interface Boundaries.
6.27. System Architecture Hierarchy Mapped to the SE Vee Model.
7.1. Design Input Requirement Verification and Validation.
7.2. Requirement Verification IPO Diagram.
7.3. Requirement Validation IPO Diagram.
8.1. Design Verification and Validation.
8.2. Zeroing in On a Feasible Design and Physical Architecture.
8.3. Design Verification IPO Diagram.
8.4. Design Validation IPO Diagram.
9.1. Production Verification.
9.2. Production Verification IPO Diagram.
10.1. System Verification and Validation Stages.
10.2. System Verification and Validation Process Artifacts.
10.3. Success Criteria Influence on System Verification and Validation Planning and Implementation.
10.4. Iterative Relationship Between Success Criteria, Strategy, and Method.
10.5. Procedure Development IPO Diagram.
10.6. Visualizations of the Project's System Verification and Validation Data and Information.
11.1. System Verification and Validation Processes.
11.2. Bottom-up View of System Verification and Validation.
11.3. System Verification IPO Diagram.
11.4. Holistic view of the SOI.
11.5. System Validation IPO Diagram.
12.1. OTS Determination as Part of Architecture and Design.
12.2. OTS Evaluation for Usage [63].
13.1. Contract Type and Approach.
14.1. Needs, Requirements, Verification, and Validation Management IPO Diagram.
14.2. Needs, Requirements, Verification, and Validation Management Activities.
16.1. Establishing Traceability Between Data and Information From Different Tools.

# LIST OF TABLES

1.1. NRVV Use Cases.
1.2. NRVV Activities as Addressed by Various Organizations and Standards.
2.1. Verification and Validation Definitions in Context.
2.2. Verification and Validation Comparisons in Terms of Outcomes.
4.1. Potential Stakeholders over the System Lifecycle.
4.2. Example Stakeholders' Perspectives and Concerns.
4.3. Example Checklist for an Elicitation Session.
4.4. Preliminary Integrated Set of Lifecycle Concepts.
6.1. Needs-to-Requirements Transformation Matrix.
6.2. Example LIR Trace Matrix.
6.3. Interface Requirements Audit Spreadsheet.
6.4. Example Interface Requirements Audit.
6.5. Example Allocation Matrix.
10.1. Tracking Preliminary and Final System Verification and Validation Status.
10.2. Example System Validation Matrix (SVaM).
10.3. Example System Verification Matrix (SVM).
10.4. Example System Verification Compliance Matrix (SVCM).
15.1. Example Implementation Status Recording and Reporting.

# 1

# INTRODUCTION

## 1.1 PURPOSE

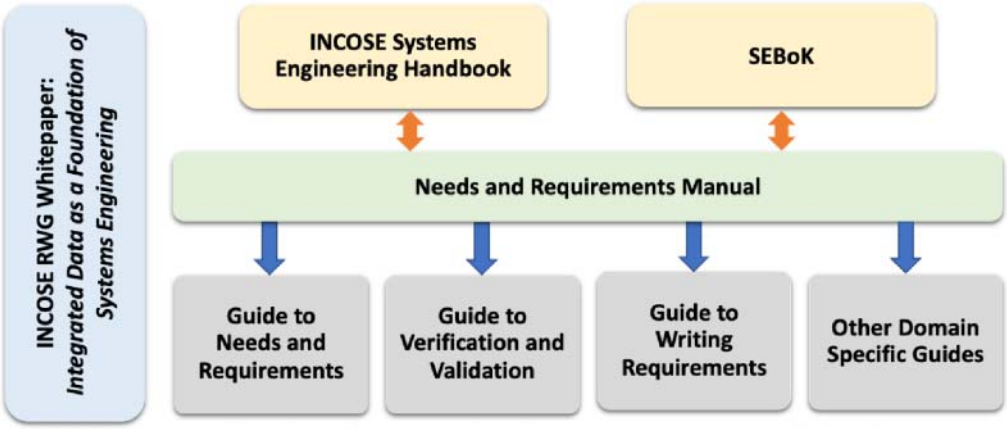
This Needs and Requirements Manual (NRM) presents systems engineering (SE) from the perspective of the definition and management across the system lifecycle of needs, requirements, verification, and validation (NRVV). NRVV are common threads that tie together all lifecycle activities and processes.

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.

*INCOSE Needs and Requirements Manual: Needs, Requirements, Verification, Validation Across the Lifecycle*,
First Edition. Louis S. Wheatcraft, Michael J. Ryan, and Tami Edner Katz.
© 2025 John Wiley & Sons, Inc. Published 2025 by John Wiley & Sons, Inc.




Original figure created by L. Wheatcraft. Usage granted per the INCOSE Copyright Restrictions. All other rights reserved.

**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<br>• Access a structured, unambiguous, and comprehensive source of information and knowledge to help learn NRVV from a data-centric perspective<br>• 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<br>• Reinforce, refresh, build upon, and renew their NRVV knowledge<br>• Tailor the concepts in the NRM to their organization's product line, processes, and culture<br>• Adopt the NRVV best practices presented in this Manual<br>• 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<br>• Suggest relevant NRVV topics to trainers for their course content<br>• Present a consistent and unambiguous ontology for NRVV.<br>• 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<br>• Align their PM and SE toolset products with a comprehensive set of NRVV activities and artifacts and underlying data and information<br>• 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<br>• Understand what a data-centric practice of SE means and its advantages<br>• Understand the value and importance of SE and NRVV activities to project success—and the importance of budgeting for and scheduling such activities<br>• Understand how measures and metrics managed within the SE toolset can help better manage product development projects<br>• Provide an accurate and comprehensive SE and NRVV reference, for both training and practitioner use<br>• Provide more accurate cost and schedule estimates for complex systems engineering projects<br>• Suggest cost and schedule savings to complex systems engineering projects, even without an engineering background |