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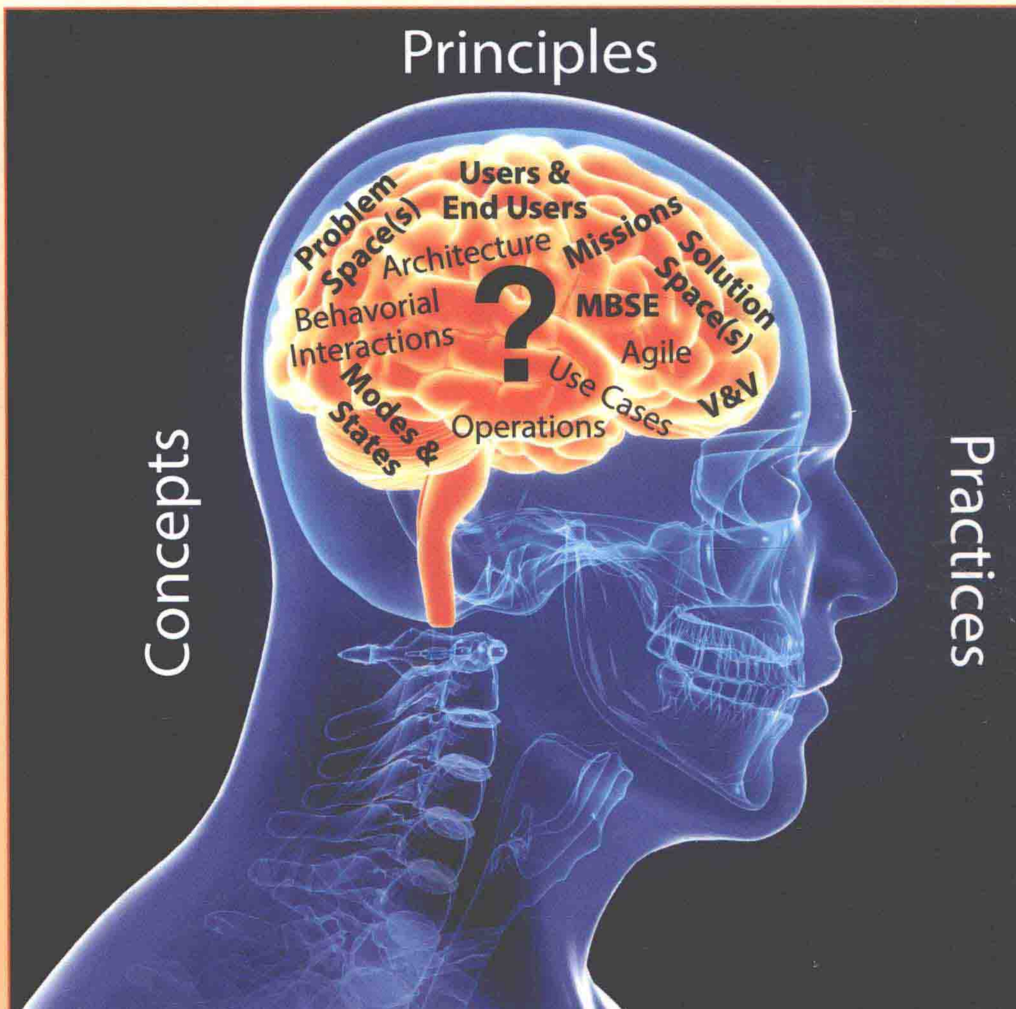
Analysis, Design, and Development

SECOND EDITION



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Foreword by Norman R. Augustine
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SYSTEM ENGINEERING ANALYSIS, DESIGN, AND DEVELOPMENT

Concepts, Principles, and Practices

CHARLES S. WASSON

WILEY

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FOREWORD

NORMAN R. AUGUSTINE

Arguably the most sought-after employees in engineering-oriented firms are systems engineers. This was certainly the case in the firm that I led at the time I led it, and I suspect that at least in this regard not much has changed. Of 82,000 engineers only a tiny fraction could have been categorized as "systems engineers;" nonetheless, they were the individuals who provided the "glue" in building our products and often were the ones that moved into management positions.

But, given the impact of their field, one can't help but ask why such individuals are so rare? One reason is that few universities even offer a degree in "systems engineering." (Most *high schools*, for that matter, don't even offer a *course* in what one might call "engineering.") Another reason is that it requires a rather special talent to cut across a broad set of disciplines—some of which would not even be categorized by most people as "technical." Further, in my experience, the best systems engineers are those who acquired a relatively deep understanding of at least one core discipline before moving into systems engineering. This seems to give them a grounding in dealing with the challenges one encounters when working with complex systems—but it also adds time to the educational process.

Further complicating matters, there is widespread disagreement, even in the profession itself, as to what constitutes "systems engineering." Is it an aspect of management? Does it have to do with the "ilities"—reliability, maintainability and availability? Does it have to do with the acquisition of major systems? Is it the process of conducting trade-offs between alternate approaches to carrying out a function or producing a design? Is it figuring out what something will cost? Is it the process of identifying solutions to a requirement … or is it determining what the requirement should be in the first place?

The answer is, "yes." It is all of these things … and more.

My own rather simplified definition of systems engineering is that it is the discipline of combining two or more interacting elements to fulfill a need. In this book, much greater insight will be given to the answer to this question. Many tools will also be presented that a systems engineer can use to address a broad spectrum of problems in design and analysis—all introduced in an understandable and carefully organized fashion.

One might conclude that with such a simple definition as the one I offer, systems engineering must be a fairly straightforward pursuit. Unfortunately, it is not. Consider the following: the simplest of all systems has only two elements, each of which can influence the other. Perhaps the canonical example would be (putting aside quarks and their cousins) a hydrogen atom. Furthermore, if one limits the interaction between the elements of the system to be binary ("on" or "off") but omni-interactive, it will readily be seen that the number of possible states of a two-element system will be just four. But if one expands the number of elements to merely seven or eight, the number of states virtually explodes.

Making matters still worse, many systems involve humans among their elements, adding unpredictability. All this is what makes it impossible to completely test a complex system in all of its possible states and makes the task of the systems engineer all the more critical. Further, among the humans affecting systems there are usually engineers, many of whom seem to embrace the code that "If it ain't broke … it needs more functions!"

To the designer of a component, say a fuel-control, the fuel-control is a system. Which it is. But to the designer of the jet engine into which the fuel control is incorporated, the engine is the system. To an aeronautical engineer, the entire aircraft is the system. And it does not stop there … since to an engineer configuring an airline the system includes passengers, agents, airports, air traffic control, runways, and still more—what is often called a system of systems. Fortunately, there are techniques to deal with such challenges in systems of systems and these, too, are described in the pages that follow.

The discipline embodied in sound systems engineering practice can have an important impact on the utility of a system. For example, a few years ago a market survey found that airline passengers wished, among other things, to get to their destinations faster. To an aerodynamicist (my original field) that meant (presuming supersonic flight over land was, at least at that time, impracticable) flying faster, which in turn meant pressing even further against the sudden drag rise that occurs as one approaches the speed of sound. Thus, the effort began to develop a "near-sonic" airliner … a difficult and costly solution.

But systems engineers interpreted the passengers' desire quite differently. They deduced that what passengers really wanted was to get from, say, their homes to an office in a distant city, more rapidly. Decomposing the relevant time-line into such segments as driving to the airport, finding a place to park and clearing security, flying, recovering baggage, and driving to the destination, they concluded that any plausible increase in airspeed would be trivial in its impact on *overall* travel time and that one should focus not on a challenging aerodynamics problem but rather on such matters as expediting security inspection, handling baggage, and speeding ground transportation. The idea of a near-sonic aircraft was thus wisely, if belatedly, discarded.

As noted, this book provides the individual interested in systems engineering with a variety of techniques to deal with such problems, techniques that systems engineers (something into which I "evolved" during my career) in the past largely learned the costly way: O.J.T. Insights will be offered into such important tasks as defining requirements, decomposing requirements, managing software, root-cause analysis, identifying single-point failure modes, modeling, conducting trades, controlling interfaces, and testing for utility as opposed to simply satisfying a specification.

Many of the more important challenges facing America, and in most cases the world, are, in effect, massive systems engineering problems. These include providing healthcare; producing clean, sustainable, affordable energy; preserving the natural environment; growing the economy; providing national security; and rebuilding the nation's physical infrastructure.

In *Systems Engineering Analysis, Design and Development,* Charles Wasson has created a guide for the practitioner. This is not a philosophical treatise or an abstract, theoretical assessment. This is a book that is for the individual who faces every-day, practical challenges relating to the various aspects of systems engineering. It is not only an important teaching device, it is a reference book of lasting value.

The logic and techniques of systems engineering are truly ubiquitous in their applicability. Whether one works in engineering, venture capital, transportation, defense, communications, healthcare, cybersecurity, or dozens of other fields, understanding the principles of systems engineering will serve one well. After all, what is there in life that doesn't involve two or more elements that influence each other?

Norman R. Augustine

Retired Chairman & CEO, Lockheed Martin Corporation
Former Under Secretary of the Army
Former Member of Princeton Engineering Faculty

PREFACE TO THE SECOND EDITION

Welcome to the Second Edition of *System Engineering, Analysis, Design, and Development* written for anyone who is accountable for specifying, analyzing, designing, and developing systems, products, or services. This Second Edition is a landmark text intended to take System Engineering (SE) to new levels of 21st-Century System Thinking. Systems Thinking that goes beyond what some refer to as "outdated, old school, and parochial" paradigms such as "Engineering the (Hardware/Software) Box" promulgated by institutions and Enterprises.

Traditional "Engineering the Box" mindsets fail to approach SE&D from the standpoint of "Engineering the System" based on User capabilities and limitations. Contrary to public perceptions, system failures are often attributable to poor System Design – "Engineering the Box" – that influences "human error" publicized as the "root cause." The reality is system failures are typically the result of a series of latent defects in the System "Box" Design that lie dormant until the right set of enabling circumstances occur and proliferate via a chain of events culminating in an incident or accident. This text goes beyond traditional "Engineering the Box" and fosters Systems Thinking to broaden insights about how to "Engineer the System" and the "Box."

The Systems Engineering *concepts*, *principles*, *practices*, and problem-solving and solution-development *methods* presented in this text apply to any discipline irrespective of type of discipline. This includes:

1. System Engineers (SE);
2. Multi-discipline Engineers—Electrical, Mechanical, Software, BioMedical, Nuclear, Industrial, Chemical, Civil, and others.
3. Specialty Engineers—Manufacturing, Test, Human Factors (HF); Reliability, Maintainability, and Availability (RMA); Safety; Logistics; Environmental, and others.
4. System and Business Analysts.
5. Quality Assurance (QA) and Software QAs.
6. Project Engineers.
7. Project Managers (PMs).
8. Functional Managers and Executives.

System Engineering Analysis, Design, and Development is intended to fill the SE void in Engineering education and to provide the concepts, principles, and practices required to perform SE. Based on the bestselling, international award-winning First Edition, this Second Edition builds on those foundational concepts, principles, and practices. This text has three key objectives:

1. To help educate Engineers who have a vision of becoming an SE or a better SE through course instruction or self-study.
2. To equip discipline Engineers and System Analysts—EEs, MEs, SwEs, etc.—with SE *problem-solving and solution development methods* that help them better understand the *context* of their work within the overall framework of the system, product, or service they are Engineering.
3. To provide Project Managers (PMs) with an understanding of SE & Development (SE&D) to facilitate better project integration with Engineering.

During the past 70 years, Systems Engineering has evolved from roots in fields such Aerospace and Defense (A&D) and proliferated into new business domains such as energy; medical products and healthcare; transportation

—land, sea, air, and space; telecommunications; financial, educational, and many others. Worldwide awareness and recognition of Systems Engineering, its application, and benefits have placed it at the forefront of one of the most sought-after fields of study and employment. In 2009, *Money Magazine* identified Systems Engineering as #1 in its list of Best Jobs in America with a 10-year job growth forecast of 45%. Besides being #1, the criticality of this profession is in stark contrast to the second place job, which had a 10-year job growth projection of 27%.

Despite its rapidly expanding growth potential, Systems Engineering is still *evolving* in terms of its methodology, discipline, and application by Users. Its application in many Enterprises is often *ad hoc*, *experiential*, and characterized by semantics and methods that often exist in lofty marketing brochures and websites. Yet, produce limited objective evidence that SE has been performed. Based on the author's experience:

- Most Engineers, in general, spend from 50% to 75% of their total career hours on average making systems decisions for which they have little or no formal Systems Engineering coursework.
- Less than 3% of the personnel—one person out of 30—in most Enterprise SE organizations possess the requisite knowledge of the concepts, principles, and practices identified in this text.
- What most people and Enterprises perceive to be System Engineering (SE) is actually an *ad hoc, trial-and-error, endless loop*, Specify-Design-Build-Test-Fix (SDBTF) Paradigm. Compounding the problem is the fact that embedded within the SDBTF Paradigm is another *trial-and-error endless loop* Design Process Model (DPM) documented in the 1960s. Users of the SDBTF-DPM paradigm acknowledge it is *inconsistent*, *inefficient*, *ineffective*, and *chaotic* in developing systems, products, or services. Yet, they continue to employ it despite the fact that it is *not scalable* to moderate or large, complex systems projects.
- The underlying rationale to the SDBTF-DPM Paradigm is that since they have used it to to develop "systems," it must be—by definition—Systems Engineering. Based on those misperceptions, the SDBTF-DPM Paradigm becomes the "core engine" within an SE "wrapper." When the SDBTF-DPM Paradigm is applied to System Development and the deliverable system fails or the customer does not like the system, they *rationalize* the root cause to be … Systems Engineering.
- Within these Enterprises anyone who has electrically, electronically, or mechanically integrated two hardware components or compiled two software modules is "knighted" as a Systems Engineer by their manager whether they have exhibited SE skills and competence in the discipline or not … everyone is "Systems Engineer."

Frightening isn't it! Unfortunately, executives and managers are often unaware or refuse to acknowledge the existence of the SDBTF-DPM Paradigm as the defacto "SE Process" within their Enterprise.

These Enterprises are easily identifiable. Ignoring or oblivious to the problem, executives and managers will challenge the SDBTF-DPM Engineering Paradigm observation. They recite metrics that quantify how they have trained XX personnel in an SE short course, YY personnel obtained a Master's degree in SE or higher, and ZZ personnel have been certified as Systems Engineering professionals within the past year. This is mindful of an old cliché that "owning a paint brush does not make someone an artist."

Despite their proclamations, project performance issues traceable to a lack of true SE education or SE courses in Engineering education refute any evidence to the contrary. There are, however, Enterprises and professionals who do understand SE and perform it reasonably well. *What are the differences between Enterprises that perform SE well versus those where the SDBTF-DPM Engineering Paradigm thrives?*

First, SE knowledge is often learned *experientially* through personal self-study and "On-the-Job Training" (OJT). Despite its significance as a critical workplace Engineering skill, the fundamentals of SE are not taught as a course in most undergraduate Engineering programs. Undergraduate or graduate level courses that are labeled as SE: (1) often focus on Systems Acquisition and Management or (2) specialty engineering equation-based courses. These courses are fine … when staged and sequenced … after … a strong, requisite foundation in understanding what a system is coupled with the ability to perform the problem-solving and solution development to actually develop a system.

Secondly, Engineering has always wrapped itself in a cloak of equations; that's the perception of Engineering by many. 21st Century System Engineering and Development (SE&D) in industry and government demands a combination of *problem-solving and solution-development* decision-making *soft skills* that precede, enable, and facilitate the equation-based *hard skills*. Engineers erroneously "knighted" as SEs who spend their days *plugging* and *chugging* equations either have a highly specialized instance of SE, misplaced priorities, or simply do not understand what is required to develop a system on-schedule, within budget, and compliant with its technical requirements!

Missing is the requisite knowledge Engineers and System Analysts need to serve as a foundation for transforming a User's abstract operational needs into the physical realization of a system, product, or service. Most SEs will emphatically state that is what they do. However, their *misinformed* perception of SE and actions reveal that they typically take a *quantum leap* from requirements directly to a physical solution and implementation (Figure 2.3). Due to a lack of a true system problem-solving and solution development methodology and skills, these efforts often result in failure or fall short of technical performance, especially in complex systems, and compliance to specification requirements.

Foundational SE knowledge requires competence in the following areas: (1) understanding and applying SE concepts, principles, and practices; (2) applying a proven *problem-solving* and *solution-development* methodology; (3) scaling SE practices to meet project resource, budget, schedule, and risk constraints; (4) structuring and orchestrating technical projects; and (5) leading multi-discipline Engineering and other types of System Development decision-making teams. Where true SE knowledge and skills are lacking, Engineering evolves into an *ad hoc, endless loop* of Build-Test-Fix with the peception that "if we create a design and tweak it enough, sooner or later we will get it right."

To address these and other issues, industry, government, and professional Enterprises have made great strides in establishing standards, Enterprise capability assessments, certification programs, etc. These are certainly *essential* for any type of discipline. However, they do not solve the *root problem* that exists concerning the lack of foundational SE knowledge. Specifically, *shifting*—correcting—the SDBTF-DPM Paradigm that permeates Enterprises, projects, and individual thinking due to a lack of substantive SE education beginning at the undergraduate level. *How do we solve the problem*?

This Second Edition builds on the author's experiences and incorporates readers' and instructors' feedback as well as advancements in SE. This includes (1) leading-edge topics and methods that enhance your knowledge and (2) provides a framework that supports pursuit of professional certification provided by organizations such as International Council on Systems Engineering (INCOSE), Enterprise level Capability Maturity Model Integration (CMMI) Assessments, and Enterprise Organizational Standard Processes (OSPs) traceability to ISO standards.

KEY FEATURES

Textbooks often include a "principles of" subtitle as marketing claims to lure readers. Readers read these texts from cover to cover and discover the lack of explicitly stated principles despite the claims. This text delivers on its Concepts, Principles, and Practices subtitle. The Second Edition:

- Includes approximately 365 principles, 231 examples, 148 author's notes, and 21 mini case studies that exemplify how to apply SE to the real world.
- Facilitates readability and quick location of key points of information based on icon-based visual aids used to highlight principles, heuristics, author's notes, mini case studies, cautions, warnings, etc.
- Consists of two levels of end-of-chapter exercises for undergraduate and graduate level course instructions: Level 1 Chapter Knowledge Exercises and Level 2 Knowledge Application Exercises.

Textbooks are often a one-time reading and disposed of on completion—donated to a library, sold back to a bookstore, or given away. It is the author's intent for this text to serve as a personal desk reference throughout your professional career subject to the evolution of SE standards, updates, etc. Professions, industries, and individuals evolve and inevitably change over time; however, fundamental systems concepts stand the test of time.

In summary, *System Engineering Analysis, Design, and Development* provides foundational SE knowledge based on the author's experience tempered by over 40 years in industry with some of the world's leading SE Enterprises and private consulting with small, medium, and large corporate clients. The next step is up to you and your Enterprise. Leverage these concepts, principles, and practices to achieve the next level of performance. Learn to *competently scale* this knowledge along with your own unique experience to meet each project's technical, resources, technology, budgetary, schedule, and risk constraints.

ACKNOWLEDGMENTS

Projects such as this demand a lot of time, inspiration, and support from a community of professionals that strive to advance the practice of the Systems Engineering. My sincere gratitude and appreciation to colleagues, instructors, authors, mentors, friends, and family who contributed to the success of the 1st Edition and to this 2nd Edition.

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Most of all … the 1st and 2nd editions of this text could not have been possible without my wife who provided reviews, comments, and unwavering support throughout this challenging project.

> *To Jean, my love … my sincere gratitude and appreciation … always and forever!*

In summary, thank you—the readers, instructors, and professionals—for the opportunity to shift traditional, narrow-scoped, Engineering and Systems Engineering paradigms to a new level of multi-disciplined 21st Century System Thinking.

CHARLES WASSON
Wasson Strategics, LLC
August, 2015

ABOUT THE COMPANION WEBSITE

This book is accompanied by a companion website:

www.wiley.com/go/systemengineeringanalysis2e.

- Level 2 Knowledge Application Exercises
- Instructional Materials
  - Chapter-Based Learning Objectives
  - Links to News Articles and Technical Papers

INTRODUCTION—HOW TO USE THIS TEXT

System Engineering Analysis, Design, and Development by virtue of its broad application to any type of Enterprise or Engineered system, product, or service is written for Engineers—Hardware, Software, BioMedical Specialty, Test, Chemical, Nuclear, etc., System Analysts, Project Engineers, Project Managers, Functional Managers, and Executives who strive to achieve System Engineering & Development (SE&D) excellence. Across that spectrum are Engineers and Analysts who may be new to SE, simply interested in learning more about SE methods to apply to their own Engineering disciplines, or seasoned professionals who want to improve and advance the state of the practice of their existing skills.

This text is written to accommodate a broad range of audiences. Writing to fulfill the needs of readers across a diverse spectrum of disciplines can be challenging. Readers who are new to SE request detailed discussions; seasoned professionals request less discussion. To accommodate such a diverse audience with varying levels of knowledge and skills, this text attempts to achieve a *reasonable balance* between communicating *essential* information about SE concepts, principles, and practices while limiting the depth due to page count limitations. As a result, our discussions will *drill down* to a particular level and provide resource referrals for you to pursue via your own personal study.

SCOPE OF TEXT

Due to the broad range of *technical* and *managerial* activities required to perform Systems Engineering and Development (SE&D) coupled with the need to limit the page count, the scope of this text focuses primarily on the *technical* aspects of SE.

As its name communicates, this text is about *System Engineering Analysis, Design, and Development: Concepts, Principles, and Practices*. This text is not about designing integrated circuits or electronic circuit boards or selecting physical components—resistors, capacitors, etc. or their deratings; design of mechanical structures and mechanisms; design and coding of software; Modeling or Simulation (M&S); developing mathematical algorithms, etc. Instead, it provides the SE concepts, principles, and practices that are *essential* for discipline-based Engineers and Analysts who perform those activities to better understand the *context* of their work products in terms of its Users, requirements, architecture, design, trade-offs, etc.

PRIMARY STRUCTURE

System Engineering Analysis, Design, and Development is partitioned into three parts:

- Part 1—System Engineering and Analysis Concepts
- Part 2—System Design and Development Practices
- Part 3—Decision Support Practices

Be Advised: Each part has a specific purpose, scope, and interrelationship to the other parts as illustrated in Figure I.1. However, for purposes of this description, to understand *why* Part 1 exists, we need to first understand the scopes of Parts 2 and 3.

Part 2—System Design and Development Practices

Part 2—System Design and Development Practices—addresses multi-discipline SE *workflow* activities

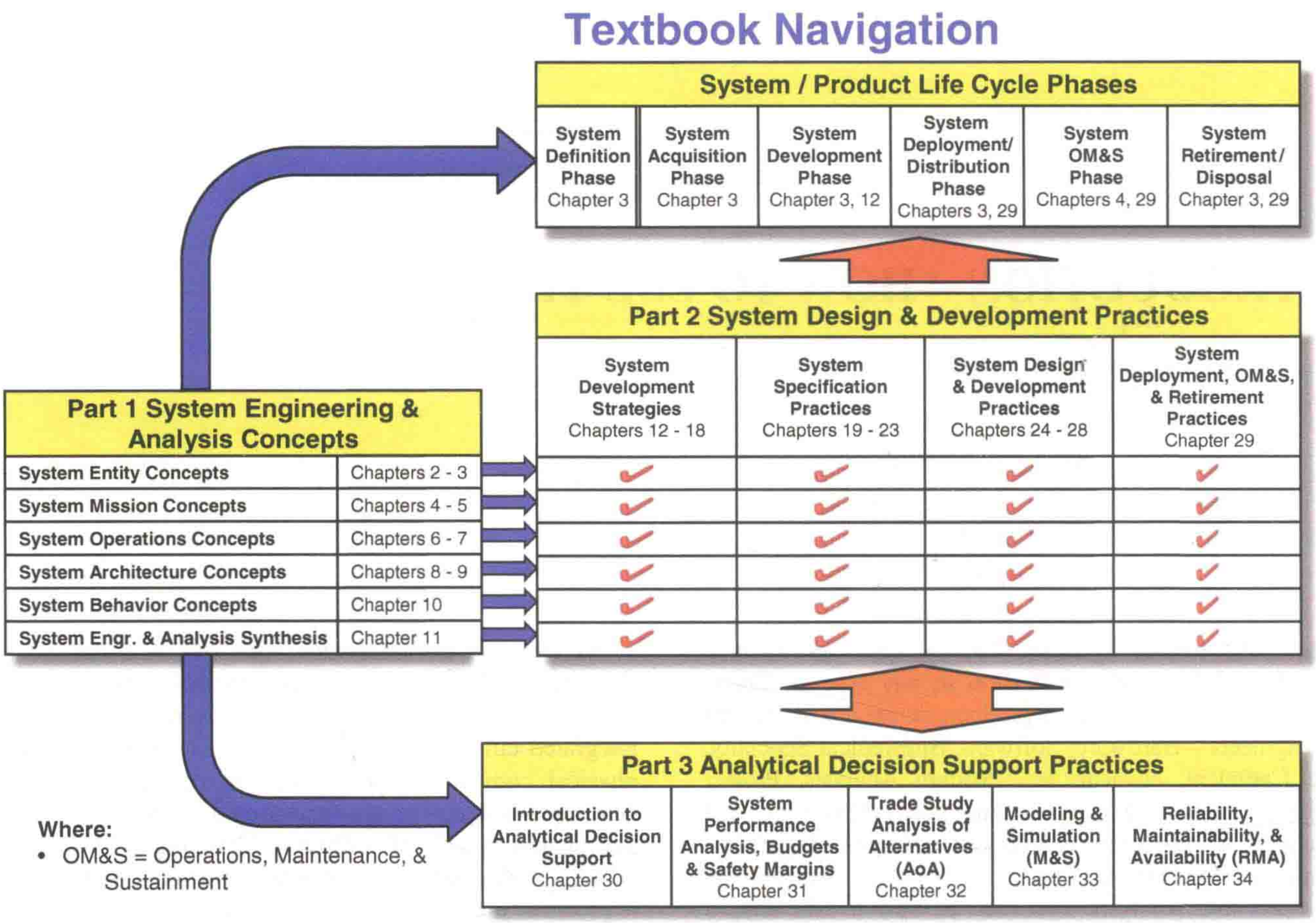

Figure I.1 Book Structure and Interrelationships

and practices required to engineer, develop, and deliver systems, products, or services. Part 2 is partitioned into four sets of SE practices that address how SE is performed not only during SE&D but also during operations performed by the User after delivery—System Deployment; Operations, Maintenance, & Sustainment (OM&S); and Retirement/Disposal. These include:

System Development Strategies

- Chapter 12 Introduction to System Development Strategies
- Chapter 13 System Verification and Validation (V&V) Strategy
- Chapter 14 The Wasson System Engineering Process
- Chapter 15 System Development Process Models
- Chapter 16 System Configuration Identification and Component Selection Strategy
- Chapter 17 System Technical Documentation Strategy
- Chapter 18 Technical Reviews Strategy

System Specification Practices

- Chapter 19 System Specification Concepts
- Chapter 20 Specification Development Approaches
- Chapter 21 Requirements Derivation, Allocation, Flow Down, and Traceability
- Chapter 22 Requirements Statement Development
- Chapter 23 Specification Analysis

System Design and Development Practices

- Chapter 24 User-Centered System Design (UCSD)
- Chapter 25 Engineering Standards of Units, Coordinate Systems, and Conventions
- Chapter 26 System and Entity Architecture Development
- Chapter 27 System Interface Definition, Analysis, and Control
- Chapter 28 System Integration, Test, and Evaluation (SITE)

System Deployment; Operations, Maintenance, and Sustainment (OM&S), and Retirement Practices

- Chapter 29 System Deployment; Operations, Maintenance, & Sustainment (OM&S); and Retirement

Part 3—Decision Support Practices

PART 3—DECISION SUPPORT PRACTICES—addresses multi-discipline SE practices such as System Analysis, Reliability, Maintainability, Human Factors, safety, etc. required to provide *timely* and *effective* decision support to the Part 2 decisionmaking practices. This includes development and assessment of rapid prototypes, Modeling and Simulations (M&S); proof-of-concept, proof-of-principle, and proof-of-technology demonstrations, to derive data to support SE&D decisions as well as to validate models and simulations. Part 3 is partitioned into the following chapters:

- Chapter 30 Introduction to Analytical Decision Support
- Chapter 31 System Performance Analysis, Budgets, and Safety Margins
- Chapter 32 Trade Study Analysis of Alternatives (AoA)
- Chapter 33 System Modeling & Simulation (M&S)
- Chapter 34 System Reliability, Maintainability, and Availability (RMA)

This brings us to the purpose of Part 1.

Part 1—System Engineering and Analysis Concepts

Most Enterprises, organizations, and projects perform the practices addressed in Parts 2 and 3. The problem is they employ the SDBTF-DPM Engineering Paradigm that is acknowledged to be *ad hoc, inefficient,* and *ineffective* as evidenced by poor performance in performing Parts 2 and 3. The reality is this is a *problem space.* PART I—SYSTEM ENGINEERING AND ANALYSIS CONCEPTS—provides a *solution space* framework for *shifting* the SDBTF-DPM Engineering Paradigm to correct these shortcomings and serves as the foundational knowledge required to competently perform the practices in Parts 2 and 3.

Part 1 is partitioned into primary concepts that enable you to understand: *what* a system is: *why* it exists—missions; *how* the User envisions deploying, operating, maintaining, sustaining, retiring, and disposing of the system; *how* systems are structured architecturally; and *how* the User envisions system behavioral responses to mission interactions in its OPERATING ENVIRONMENT. Part 1 SYSTEMS ENGINEERING AND ANALYSIS CONCEPTS consists of the following:

System Entity Concepts

- Chapter 1 Systems, Engineering, and Systems Engineering
- Chapter 2 The Evolving State of SE Practice–Challenges and Opportunities
- Chapter 3 System Attributes, Properties, and Characteristics

System Mission Concepts

- Chapter 4 User Enterprise Roles, Missions, and System Applications
- Chapter 5 User Needs, Mission Analysis, Use Cases, and Scenarios

System Operations Concepts

- Chapter 6 System Concepts Formulation and Development
- Chapter 7 System Command and Control (C2) -Phases, Modes, & States of Operation

System Architecture Concepts

- Chapter 8 System Levels of Abstraction, Semantics, and Elements
- Chapter 9 Architectural Frameworks of the SOI & Its OPERATING ENVIRONMENT

System Behavior Concepts

- Chapter 10 Modeling MISSION and ENABLING SYSTEM Operations

System Engineering & Analysis Synthesis

- Chapter 11 Analytical Problem-Solving and Solution Development Synthesis

How to Use This Text

If you are reading this text for the first time … regardless of SE experience, you are encouraged to follow the sequence of Parts 1–3 and Chapters as sequenced. Understanding PART I SYSTEM ENGINEERING & ANALYSIS CONCEPTS is the critical foundation for understanding Parts 2 and 3. Figure I.1 serves as a roadmap for quickly locating and navigating the chapters.

Once you have read the text, you will be performing project work addressed in Part 2 SYSTEM DESIGN AND DEVELOPMENT PRACTICES or PART 3 ANALYTICAL DECISION SUPPORT PRACTICES. Figure I.1 facilitates navigation in the text by enabling you to easily refer back to more detailed discussions in the other Parts.

Undergraduate and Graduate Level Course Instruction

This textbook is structured to accommodate both *upper level undergraduate* and *graduate level* Engineering and other courses. Depending on the (1) students and (2) the instructor's knowledge, skills, and industry experience, this text has also been designed to accommodate as much technical depth as the instructor wants to achieve. The instructor can treat the material as introductory or drill deeply into challenging topics.

Chapter Features

System Engineering Analysis, Design, and Development: Concepts, Principles, and Practices has been designed to incorporate specific features to facilitate readability and searches. In general, the textbook employs a common outline sequence of topics in each chapter.

- Chapter Introduction
- Definitions of Key Terms
- Approach to the Chapter (where necessary)
- Sectional Details and Discussions of Chapter Topics
- Chapter Summary
- Chapter Exercises
- References

Let's address some of the details of these features.

Definitions of Key Terms

The introduction to each chapter consists of Definitions of Key Terms that are relevant to the Chapter's discussion. Some of the definitions originate from military handbooks and standards. If you work in energy, medical, transportation, telecommunications fields, *avoid* the notion that these are not applicable to your work. As an SE, System Analyst, or Engineer, the mark of a true SE professional is the ability to work across business domains, understand the context of usage of definitions, their application, and what is to be accomplished. If your business domain or Enterprise has its own standards and definitions, *always* employ those in your work unless there is a compelling, authoritative reason to do otherwise.

Icon-Based Breakouts for Principles, Heuristics, Author's Notes, Examples, and Mini-Case Studies

SE, like most disciplines, is characterized by key points that are worthy of consideration. This includes principles, heuristics, author's notes, examples, and mini-case studies.

To facilitate readability, this text employs icon-based breakouts that also serve as easily identifiable navigation landmarks for referencing other chapters. For example, icons are encoded with XX.Y *syntax* reference identifiers where XX represents the chapter number and Y represents a sequential number indexed from the beginning of the chapter. Principle 12.4 represents Chapter 12 Principle #4, and so forth. The following is a list of icons for identifying principles, heuristics, author's notes, examples, cautions, and warnings that use this approach.

Principle I.1 *Principles represent a truth or law that governs reasoning and serves as a guide for action.*

Heuristic I.1 Heuristics represent "rules of thumb" that are not rigid but do provide insightful guidance that is worthy of consideration. As such, Heuristics are subject to exceptions depending on the circumstances.

Author's Note I.1 Author's Notes provide observations that highlight *subtle* or *noteworthy* aspects of a discussion concerning the context, interpretation, or application of a concept, principle, or practice. Your experiences may be different. You, your team, project, and Enterprise are wholly accountable for the decisions or lack of decisions you make and their consequences.

Example I.1 Examples illustrate a situation or practical application of a principle, heuristic, or SE practice.

Mini-Case Study I.1 Mini-Case Studies provide a brief description of a real-world situation, event, or incident that illustrates a principle, heuristic, example, or key point relevant to a topical discussion.

Reserved Words

Reserved words have unique *contexts* that differentiate them from general usage. For these terms, the text uses Small Caps. For example, there is a *contextual* difference in referring to your System (small caps) ... versus ... generic systems, products, or services (regular font). Reserved words occur in three categories of usage:

System Levels of Abstraction

Your System, Product, Subsystem, Assembly, Subassembly, and Part Levels.

System Types

Types of systems such as a System of Interest (SOI) composed of one or more Mission Systems and one or more Enabling Systems.

Environments

Your Operating Environment consisting of a Natural Environment, Induced Environment, or Physical Environment.

A Word of Caution I.1

Cautions are informed awareness notifications concerning conditions that represent potential risks that require special consideration. Remember—You, your team, project, and Enterprise are wholly accountable for the decisions or lack of decisions you make and their consequences.

Warning I.1

Warnings are risk-based situations that demand special attention, awareness, and recognition of decisions or conditions related to safety as well as statutes, regulations, ethics, etc. established by international, national, state, and local governments and organizations that carry severe penalties for violation. Remember – You, your team, project, and Enterprise are wholly accountable for the decisions or lack of decisions you make and their consequences.

CHAPTER EXERCISES

Chapter Exercises are provided in two forms:

Level 1 Chapter Knowledge Exercises—Represent *essential* knowledge you should have learned from the chapter.

Level 2 Knowledge Application Exercises—Represent *upper undergraduate level* and *graduate-level* exercises that challenge the reader's ability to apply Chapter knowledge to real world systems, products, or services. Level 2 Exercises are located on the text's companion website located at: www.wiley.com/go/systemengineeringanalysis2e

APPENDICES

This text consists of three Appendices:

Appendix A—Acronyms and Abbreviations—Provides an alphabetic listing of acronyms and abbreviations used in the text.

Appendix B—INCOSE Handbook Traceability—Provides a traceability matrix that links to the International Council on Systems Engineering (INCOSE) *Systems Engineering Handbook* (SEHv4, 2015) to chapters within this text.

Appendix C—Systems Modeling Language (SysML™) Constructs—Provides a brief overview of SysML™ constructs used in the text. SE employs the Object Management Group's (OMG) Systems Modeling Language™ (SysML™), an extension of the OMG's Unified Modeling Language (UML™), to model Enterprise and Engineered systems, products, and services. This text uses some of the SySML™ features to illustrate SE and Analysis concepts.

As its title conveys, this text is about *System Engineering Analysis, Design, and Development*, not SysML™; that is a separate text and course. However, to facilitate your understanding, Appendix C provides a brief overview of SysML™ constructs used in figures of this text. For more detailed information about SysML™, refer to the OMG's website.

- *Note:* UML™ and SysML™ are either registered trademarks or trademarks of Object Management Group (OMG), Inc., in the United States and/or other countries.

SUMMARY

Now that we have established *How to Use the Text*, let's begin with Chapter 1 SYSTEMS, ENGINEERING, AND SYSTEMS ENGINEERING.

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