Chapter **14**

Summary

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The system votes last.

—Jack Clemons, Senior VP Engineering (Ret), Lockheed Martin Corporation

Systems are developed to perform critical corporate and public functions. Effective and efficient systems provide great benefits to corporations (and their stockholders) and governments (and their citizens). Ineffective systems can lead to deaths (the two space shuttle tragedies), cause financial ruin of a corporation (Enron), or drastically impact the safety of a region (Hurricane Katrina) or a nation (9/11). Systems engineering and systems decision making are tools to help us deal with complex, interconnected systems designed to provide products and services in dynamic environments in the face of natural hazards and adaptive adversaries. As the above quote reminds us, there are consequences for using poor processes and making decisions that are not supported by timely, fact-based data. Systems decisions are hard enough if decision makers are provided the essential data to support timely, logical, defendable decisions. Without the essential data, systems decisions are problematic.

Systems thinking, systems engineering, and systems decision making are powerful tools to help decision makers make fact-based decisions that involve key stakeholders and consider the future operating environment of the system. In this chapter, we summarize the major insights that we hope the reader has learned from this book. In total, the book is organized into three parts: systems thinking, systems

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engineering, and the systems decision process. Each part introduces the reader to fundamental ideas in such a way as to logically construct a cohesive understanding of how to completely support decision making in the context of systems engineering and management. In the sections that follow, we summarize the themes of the three parts and key insights for successful systems engineering, concluding with some thoughts on future systems engineering challenges.

14.1 SYSTEMS THINKING—KEY TO SYSTEMS DECISION MAKING

Part I addressed the philosophy and concepts associated with systems thinking. In essence, systems thinking resists the instinctive response to decompose a systems decision problem into its smallest parts without first understanding the system as a whole. Possessing such a holistic understanding unveils the structure of a system while clearly providing a framework to explore systems interactions occurring at the seam between the system boundary and other entities in the environment. This is a critical capability for systems engineering teams because it is widely acknowledged that today's complex, interacting systems can only be understood by considering the dynamic behavior of the system with its environment.

In Chapter 1, we introduced key terminology and concepts that were subsequently developed in the book. In Chapter 2, we introduced the philosophy, language, and techniques used to engage with systems thinking. In Chapter 3, we described the structural concept of a system life cycle, illustrating the benefits of leveraging this temporal organization to perform a host of key activities, including risk management. In Chapter 4, we described the essential role of modeling and simulation in systems analysis. In Chapter 5, we presented the concepts and techniques for developing system life cycle cost analysis. Five major themes were developed in Part I and reinforced in the later chapters of the book.

14.1.1 Systems Thinking Reveals Dynamic Behavior

Systems do not exist in isolation. Systems thinking begins by carefully identifying the boundary along with a list of stakeholders who may be impacted by the decision. They exist, operate, and compete within an ever-changing environment that not only evolves in its state condition across a host of factors, but also alters the type, intensity, and purpose of interactions with the system under study. Understanding the current and future operating environment is essential to identifying critical functions, objectives, interfaces, constraints, and requirements that drive systems decision making. Systems engineers and systems managers are educated and trained to identify stakeholders, their vested interests, and any potential influences these stakeholders might affect on the system under study.

14.1.2 The System Life Cycle Must Be Considered

Major decisions affecting the well-being of systems are made during each stage of the system life cycle. While these decisions oftentimes occur during discrete time intervals, they are nonetheless interdependent. Decisions made early in the system life cycle can dramatically impact future system performance, life cycle costs, and the likelihood of specific risk events transpiring. Therefore, in supporting systems decision-making, systems teams must extend the impact horizon of decisions made in the near term to consider and predict as accurately as possible what these decisions imply for the future. This is part of proper due diligence associated with helping key stakeholders decide between candidate solutions in which a tradeoff must be considered.

14.1.3 Modeling and Simulation—Important Tools

For most modern systems, it is simply not practical to expect systems teams to construct physical prototypes of candidate solutions to provide decision makers with sufficient and substantial information concerning critical dynamic behavior. Enter modeling and simulation as the widely accepted modern day testbed for these candidate solutions. Early in the system life cycle, modeling and simulation are the essential tools to develop system concepts and help the systems designers and engineers understand system performance issues in the operating environment. Models and simulations also have many uses throughout the system life cycle to support all major systems decisions.

14.1.4 The System Life Cycle is a Key Risk Management Tool

The fundamental purpose of system analysis, development, and testing is to manage risks that have the potential to threaten the value return that a system promises. The system life cycle is a stage-and-gate process. Risk assessment should be performed at each decision gate. The risks carried forward from the previous stage and the risks expected in the next stage must be assessed at the start of each stage and managed during the next stage. The system should not enter the next stage until the key risks have been assessed and managed. Systems engineers and engineering managers have an important role in risk management identification, assessment, communication, and (identification and assessment) throughout the system life cycle.

14.1.5 Life Cycle Costing Is an Important Tool for Systems Engineering

Decision makers, clients, system owners and other stakeholders need to understand the system resource requirements so they can adequately plan and budget for the system. In addition, systems decisions must be informed by a complete understanding of the resource implications for stakeholders in each stage of the system life cycle. Life cycle costing provides useful techniques to estimate systems costs in each stage and provide key decision information required for successful system realization.

14.2 SYSTEMS ENGINEERS PLAY A CRITICAL ROLE IN THE SYSTEM LIFE CYCLE

Part II transitioned from fundamental systems thinking concepts to the practice of professional systems engineering. Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem. In Chapter 6, we provided an introduction to systems engineering. In Chapter 7, we described what professional systems engineers do. In Chapter 8, we introduced system reliability and operational suitability techniques used by systems engineers to design, develop, and monitor system operation. Four major themes were developed in Part II.

14.2.1 Systems Engineers Lead Interdisciplinary Teams to Obtain System Solutions that Create Value for Decision Makers and Stakeholders

Systems engineers must develop and lead interdisciplinary teams in each stage of the system life cycle. Systems engineers must consider the complete problem in major systems decisions in each stage of the system life cycle. The problems change in each stage, but an interdisciplinary approach to systems thinking and problem definition is always required due to the complexity of the system and the diversity of stakeholders. Systems engineers need to understand the system component engineering disciplines, work effectively with many disciplines, and know when to bring interdisciplinary teams together to solve requirements, design, test, and operational problems. Systems engineers need to focus on identifying opportunities to create value for consumers, customers, and users.

14.2.2 Systems Engineers Convert Stakeholder Needs to System Functions and Requirements

Systems engineers convert stakeholder needs to technical statements that engineering designers can use to develop the system design. Systems engineers work with future clients, system owners, systems users, and consumers of system products and services to determine the functions the system must perform and requirements the system must meet to provide products and services in the future environment. Requirements analysis and trade studies are key tools to ensure the system concepts, designs, products, and services will be affordable.

14.2.3 Systems Engineers Define Value and Manage System Effectiveness

Systems are created to provide value to stakeholders. Systems engineers define performance effectiveness measures to guide design synthesis, system validation, and test systems to solve the defined problem. Systems engineers use availability, reliability, effectiveness, and maintainability modeling to define and assess system performance. The basis for system design and validation is usually an iterative sequence of functional analysis, requirements analysis, modeling, simulation, development, test, production, and evaluation. Once the system design is validated, the systems engineer must continue to work on the successful deployment and operation of the system.

14.2.4 Systems Engineers Have Key Roles Throughout the System Life Cycle

In each stage of the system life cycle, systems engineers play important roles. Chapter 7 defined these roles in some detail. The key role of systems engineering is to assemble and lead teams to identify and resolve systems issues during the life cycle. On many programs they are systems thinker and the technical "honest broker" for the program manager. For major decisions, they analyze technical tradeoffs and present a "system perspective" recommendation to the project manager.

14.3 A SYSTEMS DECISION PROCESS IS REQUIRED FOR COMPLEX SYSTEMS DECISIONS

Part III of the text developed and described the systems decision process. For complex, interconnected, and dynamic systems involving multiple stakeholders, systems decisions may require extensive analysis, justification, reviews, and approvals by other organizations or agencies besides the program management organization. For these systems, a systems decision process may be required. In Chapter 9, we introduced our four-phase systems decision process. We also discussed when to use and when not to use the process. In Chapter 10, we introduced the three problem definition tasks: research and stakeholder analysis, functional and requirements analyses, and value modeling. In Chapter 11, we described the three solution design tasks: idea generation, alternative generation and enhancement; and cost analysis. In Chapter 12, we described the three decision making tasks: solution scoring, sensitivity analysis, and value-focused thinking. In Chapter 13, we described the three solution implementation tasks: planning, executing, and monitoring and controlling.

We summarize each of the major themes for the four phases of the systems decision process.

14.3.1 Problem Definition Is the Key to Systems Decisions

Problem definition is the most important phase of our process. The initial problem is never the final problem. Research and stakeholder analysis are key first steps for defining the problem from the perspective of stakeholders from many disciplines. The key stakeholders are clients, owners, users, and consumers. The key techniques of stakeholder analysis are interviews, focus groups, and surveys. Each has advantages and disadvantages. The second set of tasks include functional and requirements analyses. Systems engineers must identify what functions a system must perform. As we progress through the system life cycle, additional information (requirements, constraints, interfaces, etc.) will be developed. The third task is value modeling. Systems engineers must define the objectives and the value measures that will guide solution development to create value for consumers of system products and services. These three tasks are critical for the systems decisions in each life cycle stage.

14.3.2 If We Want Better Decisions, We Need Better System Solution Designs

The key to architecture, system-of-systems, and systems design is to create candidate solutions that provide great value for clients, owners, users, and consumers. Creative design engineers are the key to better design solutions. The creativity techniques introduced in Chapter 11 can help the designers. Modeling and simulation can help ensure that alternatives are feasible, effective, and efficient. We need to screen the infeasible alternatives and then use value-focused thinking to help identify opportunities to create better candidate solutions. We need to develop cost models during solution design to ensure that the candidate solutions are affordable.

14.3.3 We Need to Identify the Best Value for the Resources

When we complete the solution design phase, we have several candidate solutions. The purpose of the decision-making phase is to provide the essential information that the decision maker needs to make a timely, sound, and defensible decision. Each of the candidate solutions should be scored using the most appropriate method (operational data, development data, test data, modeling and simulation data, or expert opinion). The systems engineer should identify the most sensitive assumptions of the analysis and identify and analyze key uncertainties and risks affecting success. Finally, the systems engineer should use insights from scoring and sensitivity analysis to encourage the design team to create higher value solutions. We assess the system resources with life cycle cost models. When time runs out (as it always does!), we present the nondominated solutions and let the decision makers choose which system solution provides the best value for the resources. Our oral presentation and written reports must be clear, concise, and cogent.

14.3.4 Solution Implementation Requires Planning, Executing, and Monitoring and Controlling

The implementation of the solution can be very frustrating. The key stakeholders must support the implementation of the system solution. A sound decision can fail to achieve the planned value due to poor implementation. The keys to solution implementation are previous stakeholder involvement, good task identification, clear task assignments, development of performance measures, feasible monitoring procedures, clear assessment plan, and effective control measures. An important part of solution implementation is risk identification, assessment, communication, and management.

14.4 SYSTEMS ENGINEERING WILL BECOME MORE CHALLENGING

As systems become more complex, interconnected, and dynamic, it is difficult to imagine that the task of systems engineers will become easier. As more stakeholders become interested in the consequences of systems decisions, more stakeholders will become interested in systems decisions that will affect them. We believe that increasing complexity, increasing interconnectedness, increasing security challenges, and increasing stakeholder interest will make the systems engineer's job interesting and challenging for the foreseeable future.