Chapter **1**

# Introduction



## 1.1 INTRODUCING LEAN SYSTEMS ENGINEERING AND LEAN ENABLERS FOR SYSTEMS ENGINEERING

This book was written for two purposes: to popularize the emerging field termed *Lean Systems Engineering (LSE)*, and to serve as a textbook and reference for the first major product created under it: *Lean Enablers for Systems Engineering (LEfSE)*.

The discipline of *Systems Engineering* (SE) was created to help with the development of complex systems that must work unconditionally. It was first shaped in the ballistic missile program by Si Ramo[1] and Dean Wooldridge in 1954, with the first formal contract to perform systems engineering and technical assistance (SETA). Under this contract, Ramo and Wooldridge developed some of the first principles for SE and applied them to the ballistic missile program—considered one of the most successful major technology development efforts ever undertaken by the U.S. government [Jacobsen, 2001]. SE is the practical engineering realization based on *systems thinking*, a comprehensive design process of a system that satisfies all customer needs during an entire system life cycle. The process demonstrates reliable

[1] Si Ramo once told F. Brown [SELP Director, Loyola Marymount University, personal communication] the first use of systems engineering in modern times could be said to have started at AT&T when they faced assembling a world-wide telephone system. AT&T, however, did not consider it systems engineering and did not use that name.

*Lean for Systems Engineering with Lean Enablers for Systems Engineering*,
First Edition. Bohdan W. Oppenheim.

execution of system development programs and leads to extraordinary technological successes in space, air, naval, and ground systems and weapons. The International Council on System Engineering (INCOSE), the professional society of Systems Engineers, offers the following definition of Systems Engineering:

> *Systems Engineering (SE)* 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, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.
>
> —INCOSE

Balance between technical and business success is one of the critical aspects of high-quality SE. Regretfully, during the past decade, in some government programs inadequate incentives tended to throw the balance off. Namely, system or mission assurance was incentivized while short program schedule and low cost were not. In consequence, in many recent programs the schedule and budget were exceeded, and the final schedules and budgets were significantly extended beyond comparable programs of earlier periods. In extreme cases, instead of *engineering complex systems*, the SE process has deteriorated to a *complex bureaucracy of program artifacts* with no technical success in sight. This book describes how *Lean Thinking* is applied as a "rescue" to SE, to achieve both technical and business successes.

*Lean Thinking* (or, briefly, *Lean*) is a holistic paradigm that originated at Toyota[2] and focused on delivering value to the customer while removing waste from all activities.

[2]Throughout its history, Toyota has demonstrated an amazing and unprecedented record of quality and has served as the ideal for best corporate practices in a broad range of activities—product development, manufacturing, supply chain management, enterprise management, and exemplary human relations. The two well-published pillars of Toyota success are *Respect for People and Continuous Improvement*. A good fraction of the enablers presented in his book have been based on these extraordinary Toyota practices. The trust in Toyota was temporarily shaken in late 2000s when media started publishing stories about the unintended acceleration of Toyota cars. In January 2010, Mr. Akio Toyoda, the newly appointed CEO of Toyota Motor Co., during the public hearing by U.S. Congress, started with words of apology for the apparent unintended acceleration problems of some recent Toyota cars. In his testimony he said: "Quite frankly, I fear the pace at which we have grown may have been too quick. I would like to point out here that Toyota's priority has traditionally been the following: *First; Safety, Second; Quality, and Third; Volume*. These priorities became confused . . . and I am deeply sorry for any accidents that Toyota drivers have experienced" (ABC News, Feb. 24, 2010). Media accused Toyota of ignoring the problem and blamed the company for hundreds of accidents, including fatal ones. This dramatic story was reversed in 2011. In early 2011 J. Liker and T. Ogden published a book *Toyota Under Fire* which provided evidence completely exonerating Toyota. The book quotes the results of

*Lean* dramatically reduced car development and production times and costs while increasing product quality and stakeholder satisfaction, and became a standard practice in most manufacturing industries. Inspired by these successes, *Lean* was applied in many other domains, including supply chain management, product development, administration, accounting, healthcare, and government, in each case creating significant well documented benefits.

> *Lean Thinking (Lean):* "Lean Thinking is the dynamic, knowledge-driven, and customer-focused process through which all people in a defined enterprise continuously eliminate waste with the goal of creating value."
>
> —LAI EdNet

*Lean Systems Engineering (LSE)* is an emerging field representing the synergy of *SE* and *Lean*.

> *Lean Systems Engineering (LSE):* The application of lean wisdom, principles, practices and tools to systems engineering in order to enhance the delivery of value to system's stakeholders.
>
> —LSE Working Group

The *Lean* in Lean SE should be regarded as the process of amending the well-established, traditional SE process with the wisdom of *Lean Thinking*, rather than replacing SE with a new body of knowledge. Put emphatically:

> *Lean Systems Engineering:* does not mean "less systems engineering," but rather more and better SE, with better preparations of the enterprise processes, people and tools; better program planning and frontloading; better

a major study performed on request of U.S. Congress by NASA under contract to the U.S. National Highway and Transportation Safety Board. The results were announced by Secretary Ray LaHood on Feb.8, 2010. NASA [2011] results were summarized as follows: "Two mechanical safety defects were identified by NHTSA . . . sticking accelerator pedals and a design flow that enabled accelerator pedals to become trapped by floor mats. These are the only known causes for the reported unintended acceleration incidents. Toyota recalled nearly 8 million vehicles in the U.S. for these two defects. The Liker and Ogden [2011] book indicates that the numerous reported cases of unintended acceleration were caused by drivers using a wrong pedal, a phenomenon known to all car companies and highway police alike; and that there was only one proven deadly accident due to pedal entrapment, and one other accident caused by the car owner using a wrong floor mat. Thus, strictly speaking, Mr. Toyoda's apology turned out to be unnecessary, but, characteristically for Toyota, it was never withdrawn. In addition, Toyota instituted numerous additional organizational safeguards and precautions, including a brake override system that stops the car even when the gas pedal is wide open. This dramatic episode demonstrates the uninterrupted focus on safety, quality, and customer satisfaction by Toyota.

workflow management; and better program management and leadership with higher levels of responsibility, authority, and accountability. The benefits of *LSE* are immediately visible in better SE processes, as well as in the streamlined execution of the program. There is less waste, waiting, and rework; more predictable and robust program flow; lower overall program cost and shorter schedule, and creation of better value to the customer.

The fundamental feature of *LSE* is to perform all preparations and planning of the people, processes, tools, and individual tasks well enough so that the tasks can be executed ***right the first time***,[3] creating customer value while minimizing waste. Under the *LSE* philosophy, system success or mission assurance is non-negotiable, and any task which is legitimately needed for success must be included in the program. It should be well-planned and executed with minimum waste.

*Lean Enablers for Systems Engineering (LEfSE)* is the first major practical product created under LSE, and is the main topic of this book. LEfSE is a checklist of 147 practices formulated as dos and don'ts of SE and some closely related aspects of Product Development (PD) and Enterprise Management (EM), including supply chain management. The intent of LEfSE is to offer comprehensive and actionable practices to the profession, with the objective of improving overall performance of SE and the PD program it serves; strengthen the value created by the program; increase the level of satisfaction of stakeholders; and reduce waste, program cost, and time. Most of the effort in developing LSE and the LEfSE was conducted by the LSE Working Group (LSE WG) of INCOSE. This was an intensive and rigorous two-year process by 14 experts, supported by members of the WG, and endorsed by surveys and by benchmarking with recent NASA and Government Accountability Office (GAO) recommendations for system development.

The surveys confirmed that practitioners regard LEfSE as both important, and not yet widely used. Benchmarking showed excellent convergence between LEfSE on one hand and NASA and GAO recommendations on the other, with LEfSE usually more detailed, comprehensive, and actionable than the GAO recommendations. The development of LEfSE is summarized in Chapter 6 of this book.

Version 1.0 of LEfSE was released to INCOSE and to the public in January 2009. In 2010 the LEfSE were recognized with two following prestigious awards:

- The INCOSE Product of the Year
- The Shingo Award for Research and Publication

These independent recognitions from both *SE* and *Lean* communities are regarded as an important step in validating LEfSE.

[3]The expression ***right the first time*** refers to both single-pass tasks as well as engineering iterations and other complex activities, which also must be regarded as tasks that need to be well planned, designed, and executed so that they can be completed robustly in a predictable time without wasteful rework.

After the LEfSE were released to the public on the INCOSE web page,[4] the author and several of his colleagues on the development team were invited to offer numerous (forty at the time of this writing) workshops, tutorials, webinars, and seminars to industry, governments, INCOSE meetings, and universities in the U.S., China, Finland, France, Italy, Israel, Netherlands, Norway, Poland, Singapore, Sweden, and the United Kingdom. Over 2000 participants took part in these professional events, generally excellently received. In many of these sessions, participants asked for more explicit information about the enablers than was possible to present in the short sessions. This book is a direct response to these requests.

As already mentioned, this book is intended as both an introductory textbook on LSE and a textbook and reference for Lean Enablers for SE. The material presented is broad in scope and it applies to the development of all types of complex systems in all domains, both in commercial and government programs. We hope that LEfSE will benefit Systems Engineers and other PD engineers and managers, professionals involved in systems acquisition both in industry and government, project managers, and faculty and students of these fields.

Even though the material presented in this book applies to all domains and all program types, government programs are mentioned most often for two reasons. First, SE is mandatory in such programs while it is not in commercial programs, thus the body of experience from government programs is significantly larger. Second, the amount of waste in governmental programs tends to be significantly higher than in commercial programs, which makes it a fertile ground for Lean thinkers.

The author chooses to explain selected enablers by comparing them to some current industrial and governmental practices that are less than perfect. The author hopes that the reader will accept this approach as constructive criticism leading to improvement of our programs, rather than "bashing" of the traditional practices. To repeat with emphasis: The traditional SE process is regarded as sound, capable of delivering successful complex systems, but not as good as it could be, and which we therefore propose to improve using Lean.

Both SE and Lean are a mix of art and science, and the art of effective teaming plays a critical role in SE. Some programs can be compared to the effort of climbing Mt. Everest or competitive racing in a storm—extraordinary teams pursuing difficult challenges against heavy odds. The Apollo, U2, F117, Boeing 747, nuclear submarine, and the Prius car programs come to mind as examples. Such programs inspire young people to choose a career in engineering. In sad contrast, creation of bureaucratic SE artifacts in isolated cubicles is not what inspiriting engineering was promised to be. The best programs must involve leadership, teamwork, enthusiasm, passion, inner energy, and joy in addition to hard competence and experience. The author tried to include these intangible elements in the book, in order to enthuse the reader about the potential of Lean,

[4]The web page of the Lean Systems Engineering Working Group of INCOSE is public and accessible to everyone. Appendix 1 provides the web address and a summary of the site content.

which is capable of drawing the best from us and motivating us to engineer extraordinary systems using extraordinarily efficient programs.

SE is a part (in fact, the most critical part for success) of the larger Product Development (PD) effort. SE has been called the nervous system of PD [Hitchens, 2007], planning, controlling, and monitoring in real time all functions of the PD "body." However, many enterprises have structured SE to be a separate function (department) that supports all their PD programs. This led to a linguistic dichotomy, "SE and PD". In this book the term "SE and PD" should be interpreted to mean "SE and other elements, parts, activities, etc. of PD."

The traditional SE process is described in a number of manuals: INCOSE SE Handbook, the ISO 15288 standard, NASA and Department of Defense SE Manuals, Defense Acquisition University manuals, and numerous manuals created by individual defense and civilian companies. Arguably, the manuals describe essentially the same body of knowledge and the same *traditional* SE process with varying degrees of detail, emphasis, and user friendliness. Since the present project has been carried out under the auspices of INCOSE, and because the author regards the INCOSE SE Handbook v.3.2, 2010 as an excellent and user-friendly document, the present text makes references to that document only. Version 3.2 of the Handbook includes a short chapter on Lean Thinking. The first enabler of LEfSE explains that practitioners should continue using all processes described in the Handbook, adding Lean practices listed in LEfSE.

## 1.2 ORGANIZATION OF THE BOOK

The book is organized as follows.

Chapter 2 takes the reader through a brief historical review of earlier industrial paradigms, setting Lean Thinking in the context of Total Quality Management (TQM), Concurrent Engineering (CE), and Six Sigma.

Chapter 3 presents Lean Thinking fundamentals, including the concepts of value, waste, and the process of creating value without waste, as captured into the six Principles of Lean Thinking. The Principles are called Value, Map the Value Stream, Flow, Pull, Perfection, and Respect for People. The fundamentals are included to make the book self-contained, but the reader unfamiliar with Lean will surely benefit from reading the transformational book *Lean Thinking* by J. Womack et al. [1996]. Readers who understand Lean manufacturing but have not been exposed to Lean Product Development (LPD) should read this chapter because it sets Lean fundamentals in the PD context.

The ability to recognize waste in Product Development is a critical skill in LSE. Waste should be regarded as a productivity reserve. Exposing waste aids in streamlining the program and creating time and cost buffers, thus helping the program to meet schedule and budget. Some wastes are self-evident and incontestable (e.g., waiting, or defects), but others may be less obvious, particularly to Systems Engineers who have to struggle for enough budget and time to execute a program well. Therefore, the discussion of waste is an important part of the book.

Chapter 4 describes the fast growing field of Lean Product Development, including a review of literature and the progress to date. Arguments are presented in support of the thesis that the application of Lean Thinking to Product Development has become mature enough for immediate use in programs.

In Chapter 4, Section 4.2 describes a highly efficient holistic process called Lean Product Development Flow (LPDF) developed by Oppenheim [2004] for organizing smaller and low-risk PD programs. LPDF was created as a contribution to LSE, but is an earlier and totally separate effort from LEfSE.

Chapter 5 presents the emerging field of LSE. We start with a review of recent literature documenting both successes and problems in technology programs and justify the need for better SE, with less waste, leading to LSE. We also introduce the INCOSE Lean SE Working Group. This chapter ends with a discussion of value in LSE.

Chapter 6 describes the strategy used for the development of LEfSE, and the endorsement steps. The interested reader will find details of the development process in a comprehensive journal article by Oppenheim, Murman, and Secor (2010), which are not repeated here. We only briefly describe the endorsement efforts by peers, including a survey completed by practicing Systems Engineers, and benchmarking of LEfSE with recent recommendations, which were published by NASA and Government Accountability Office (GAO) when this project was nearing completion. The reader will find that the survey ranked all enablers as (paraphrasing) either *important* or *very important*, and not yet used widely, confirming the importance and the need for LEfSE in the SE practice. The LEfSE have been found to be totally convergent with the NASA and GAO recommendations, but are more comprehensive, detailed, and actionable.

The version of LEfSE presented in this book is regarded as mature enough for presentation to the professional community. However, the intent is to continue involving the community of practice in gathering data and experiences to continue improving the LEfSE product.

Chapter 7 is the main and longest part of this book. It presents the enablers in a standard tabular form for easy reference. The enablers are organized under the six Lean Principles. The text under each Lean Principle begins with a short summary of the listed enablers.

Each enabler or closely related group of enablers is described in a separate table listing the value promoted and the waste prevented by the enabler(s), an explanation of the enabler(s), recommended implementation, lagging factors, and recommended reading list.

In most cases, each table covers only one enabler. In other tables, several closely related enablers are discussed together in order to facilitate reading and implementation.

Chapter 8 contains general guidance for implementing LEfSE. We hope by that time, the reader will be familiar with LEfSE in Chapter 7. We suggest how to select and prioritize the enablers for implementation, and recommend practical steps.

In Section 8.2 we include some early feedback and results from the companies and programs trying to implement LEfSE, and other relevant studies. At the time

of this writing, some of these success stories are still fragmentary and lacking scholarly rigor, but they demonstrate the powerful potential of the Lean approach. The sources claim that with only a few Lean enablers implemented, various program time/cost elements were reduced between 20 to 40%, achieved a ROI of 5, and improved the workplace morale, product quality, and customer satisfaction.

Appendix 1 summarizes the content of the INCOSE Lean SE Working Group webpage.

Appendix 2 presents a mapping of Lean enablers onto the 26 processes listed in the INCOSE SE Handbook version 3.2. This mapping project was initiated by INCOSE, but has not yet been approved by that organization. This appendix also contains a short discussion of program lifecycle frameworks other than the SE processes.

Two glossaries are included—one for abbreviations, and one for idioms, colloquialisms, and foreign expressions used in the fields of SE and Lean. These items are ***written in bold italic font*** in the text. *The italic font alone is used when introducing important new terms, and for emphasis*. **Bold font** (as in the next sentence) is used for greater visibility when navigating through these pages.

**How to use this book?** Those readers who are eager to become productive can skip Chapter 2, with its historical review, and Chapter 6, which covers the development of LEfSE. Readers who are experts in Lean Thinking and familiar with fundamentals of Lean Product Development may go directly to Section 4.2 of Chapter 4 for use as a reference for the LPDF method, and to Chapter 7, as a reference for improving the practice of SE with LEfSE. Readers who are new to Lean Thinking should first read Chapters 1 and 3–5.