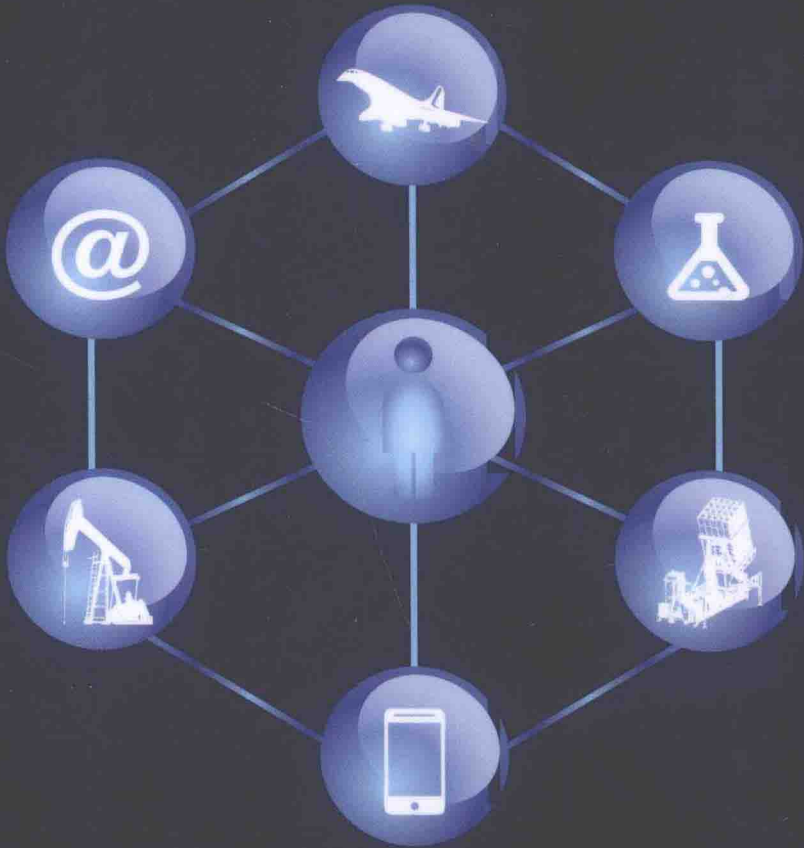


Avigdor Zonnenshain • Shuki Stauber

Managing and Engineering Complex Technological Systems



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MANAGING AND ENGINEERING COMPLEX TECHNOLOGICAL SYSTEMS

AVIGDOR ZONNENSHAIN AND SHUKI STAUBER

The Gordon Center for Systems Engineering, Technion, Haifa, Israel

WILEY

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

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Library of Congress Cataloging-in-Publication Data:

Zonnenshain, Avigdor.

Managing and engineering complex technological systems / Avigdor Zonnenshain, Shuki Stauber.

pages cm

Includes index.

Summary: "This book is based on a qualitative study that includes dozens of in-depth interviews with experts in the systems engineering field"—Provided by publisher.

ISBN 978-1-119-06859-4 (hardback)

1. Systems engineering. 2. Industrial management. I. Stauber, Shuki. II. Title.

TA168.Z66 2015

620.0068—dc23

2015000703

Typeset in 10/12pt TimesLTStd by SPi Global, Chennai, India

Cover design by Zvi Fedelman.

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

1 2015

To my beloved wife, Michaela, for her love, friendship,
and continuous support

Avigdor

To Yaron and Sharona, my lovely offspring
Think before act, do not spare planning

Shuki

WORDS FROM INCOSE PRESIDENT

Dear Systems Engineers,

I am proud to be a systems engineer.

Systems engineers have an important role in developing systems for the benefit of mankind and the world.

The study on Systems Engineering has Many Facets, which is documented in this book, is very important for the Systems Engineering community, as it presents for the first time different views and various aspects of systems engineering as expressed by 24 experts who have been interviewed for this research. These experts come from different countries, cultures, and backgrounds.

This study is a great asset for INCOSE as a training material and as a promotional document for the systems engineering community as it presents the diverse, rich, and colorful roles of the systems engineer.

I am proud to be part of this effort as one of the experts to be interviewed. It gave me the opportunity to communicate my views and vision on the important values of the systems engineer.

I congratulate the leaders of this initiative – Shuki and Avigdor, and I express my thanks to the Gordon Center for supporting this study.

John A. Thomas, ESEP
INCOSE President
(2012–2013)

WORDS FROM THE HEAD OF THE BERNARD M. GORDON CENTER FOR SYSTEMS ENGINEERING, TECHNION

In the early days of my term as dean of the Technion's Aerospace Engineering Faculty (1995–1998), I received a request from the industry to devise an academic program that taught systems engineering. Until that time, academic activity in systems engineering in Israel was fairly limited and spread out among different academic units of the Technion and other institutions. The fact that the industry officials had chosen the Dean of the Aeronautics and Space Faculty was no coincidence. Globally, systems engineering activity originated in the aerospace and defense industries. Being aware of the importance of this subject, and of the Technion's historical role as the promoter of engineering knowledge and achievement in Israel, I accepted the request without hesitation. The multidisciplinary and interdisciplinary nature of systems engineering made it clear that the program had to be an inter-faculty program – with more than one academic unit involved. Indeed, since its founding, the program has been managed by a committee of representatives from several different faculties. Moreover, I recognized that systems engineering was a field that, probably more than any other, had close ties to the industry. In light of this, the committee founded to determine the objectives and character of the studies included high-ranking industry representatives, in addition to its traditional academician members. The plan devised by the committee, even in its early versions, was for the program to grant its graduates a master's degree. Candidates had to have a bachelor's degree and a certain minimum of professional experience in their field of expertise, before they were even considered for the program.

After its launch, the program received a lot of interest, and demand was much higher than we had expected. Today, less than 15 years since, the program boasts over 1000 graduates and students. The systems engineers trained by it are spread out throughout the Israeli defense and civilian industries, offices, and organizations. They have tremendous influence on the integration of systems engineering procedures and systems thinking in Israel. One would be hard-pressed to find a major project in Israel that does not have graduates of the program among its teams, many of them occupying high ranking positions.

A considerable boost to systems engineering in the Technion and in the whole of Israel was brought on by the establishment of the Bernard M. Gordon Center for Systems Engineering. The center was founded thanks to the help and generous contribution of Dr. Gordon, a highly accomplished engineer from the United States, who recognized the importance of this cause. The center has allowed us to deepen the ties between the industry and the academy, and to begin research in systems engineering, some of it in close collaboration with the industry. Additionally, the center organizes conferences and seminars, invites foreign experts to hold lectures and workshops, and encourages the Israeli technological community to adopt modern systems engineering methodologies. Although, in recent years, awareness of the benefits of systems engineering has given it a firmer grasp in ever-growing parts of the industry, there are still engineering fields where it is virtually nonexistent. In light of this, the Gordon center believed it very important to perform the study that eventually led to the writing of this book. I believe that this book, based on interviews with local and foreign systems engineering experts, presents a broad view of the systems engineering field, the challenges it is facing, its contributions, its benefits, and the challenge it sets before those who wish to embed it into their industries and organizations.

Systems engineering has brought valuable insights on analyzing and optimizing the workings of complex, multidisciplinary and interdisciplinary systems, which can and should have an impact beyond the boundaries of the technological world. Health-care systems, social systems, and many other systems can benefit from adopting the methodologies systems engineering has developed. This is why it is so very important for those who are not involved with engineering or technology to be aware of and have access to systems engineering methodologies. With this end-goal in mind, the authors of this book have succeeded in presenting a picture that can be grasped by readers with no special technological background.

I would like to thank all the interviewees who have taken the time to participate in the interviews and helped put them in writing. I am grateful to Dr. Avigdor Zonnenshain and Mr. Shuki Stauber for their dedication to the writing of this book and for the great effort they have invested in it. I hope you find this book enjoyable, and I believe it will help spread the awareness of the many benefits of systems engineering. I hope this book will encourage its readers to use modern insights, knowledge, and tools to make better systems.

Prof. Aviv Rosen
Head of the Bernard M. Gordon Center for Systems Engineering,
Technion – IIT, Haifa

WORDS FROM THE PRESIDENT OF THE ISRAELI ASSOCIATION FOR SYSTEMS ENGINEERING-INCOSE_IL

Those who practice systems engineering have always intuitively known the right way to work on systems projects, but, until now, there was not enough quantitative data to support this perception. In recent years, studies have shown significant high correlations between investment in systems engineering (as part of a project's total cost) and project success, measured by meeting planned performance, budget, and schedule. High correlation was also found between the project's chief systems engineer's management and technological leadership abilities and the project's success.

It appears that the previous dilemma of whether to invest in systems engineering has now been resolved. Israel's defense industry and government organizations, the birth-places of Israeli systems engineering, have long since understood this, and, in recent years, we have been witnessing the introduction of systems engineering approaches and processes into small- and medium-sized "civilian" enterprises as well.

Here, in the Israeli Society for Systems Engineering, we are convinced that in Israel, of all places, systems engineering should be treated as a strategic asset and as a discipline in which we hold a major relative advantage. For this reason, we decided that alongside strengthening systems engineering in defense organizations, and tightening the cooperation between industry, government, and academia, we should also act to assimilate the huge body of knowledge accumulated on the subject to all of Israeli industry. We intend to achieve this by research, education, and activities aimed at sharing knowledge of systems engineering.

This book fits in well with these objectives. It provides an exciting opportunity to experience a close encounter with a vast pool of knowledge and insights of 22 systems engineering experts.

The editors of this book are two leading experts: Dr. Avigdor Zonnenshain, a senior, experienced systems engineer, who recently retired from his position at Rafael and currently works at the Technion's Gordon Center for Systems Engineering, and Shuki Stauber, a reputable expert on management and author of numerous management books.

On behalf of the Israeli Society for Systems Engineering, I would like to thank them for their valuable contribution to the advancement of systems engineering in Israel.

Best regards,

Professor Moti Frank,
President of the Israeli Association for Systems Engineering – INCOSE_IL
(2013–2014)

WORDS FROM THE WRITERS

Systems Engineering is a dynamic discipline that changes and evolves constantly, adapting to the changes in its working environment. It is affected by factors like technological change, developments of interfaced disciplines, research findings, and lessons learned from experience in the industry, to name only a few.

In the 40 or so years of my career, I, too, have personally experienced various aspects of and perspectives on systems engineering and the applications of systemic approaches in the industry and academia. I have applied a holistic, systemic approach to a number of fields, including: systems safety and reliability, systems experiments, integrated logistic support, total quality management and engineering, management and development of systemic-technological projects, and corporate social responsibility.

These are the thoughts and experiences that led me to the idea of a qualitative study of the various aspects of systems engineering, carried out in the form of interviews with local and international systems engineering experts. To ensure the high level and professionalism of the interviews and writing, we employed the services of Shuki Stauber, a professional interviewer and writer, who specializes in management.

The interviews in this book will help the readers learn about the origins and evolution of the systems engineering discipline and gain a personal familiarity with systems engineering experts: their experience, opinions, and attitudes in this field. For this reason, we chose to call this study "The Many Faces of Systems Engineering." We sought answers to the questions: What are the different aspects of systems engineering? What different perspectives will the experts interviewed in this framework have to offer?

We approached over 20 experts, both locally and worldwide, representing a wide spectrum of occupations and experiences, both in the industry and in academia.

All experts responded to our request and agreed to participate in the study with great enthusiasm, presenting us with clear, detailed accounts of their experiences and opinions on this study's areas of interest, including answers to questions such as: How does systems engineering handle technological complexity and the ever-changing needs of the clients? How is systems engineering actually implemented in various projects and organizations? How does the systems engineer serve as both manager and leader? All the experts we approached applauded the initiative, were glad of the opportunity to present their approaches, and showed great appreciation for the possibility that their opinions shall be banded together and included in a book that would summarize the findings of the study.

It should be noted that my personal acquaintance with dozens of systems engineering experts in Israel and worldwide has helped us recruit this study's participants. In fact, we have yet to hear a single refusal ...

This study has also helped me achieve some historical closures, one of them being my meeting with President of Lockheed Martin, Norman Augustine, whose acquaintance I had had the pleasure of making back at Martin Marietta, when he, as its president, had been navigating the collaboration with Rafael, and I had been a member of the team that facilitated its establishment. Back then, he had been the object of my admiration, and now, I have had the privilege of meeting him and interviewing him for this study.

The choice to recruit Shuki Stauber, a professional writer and interviewer specializing in management fields, to help carry out this study, was both conscious and educated. We wanted the interviews to be very professional and the writing of their summaries to be accessible to all. This meant that readers from outside the systems engineering community should be able to read and understand the findings and insights contained herein and even apply them to their respective occupational areas. It is my opinion that the "gamble" of recruiting Shuki has paid off beyond our wildest expectations: Shuki listened to and learned the various aspects of systems engineering and has managed to put the findings into words that anyone would be able to understand. I can say without hyperbole that Shuki Stauber is the best systems engineer among all the authors of management books in Israel.

I would like to thank the head of The Gordon Center for Systems Engineering at The Israel Institute of Technology (Technion), Professor Aviv Rosen, for bravely taking up the gauntlet I had tossed his way, in the form of this extensive study. Professor Aviv Rosen handled the financing of the study, directed its movements, and actively participated in most of the interviews. His professional contribution to this study is nothing short of priceless.

I hope that you find this book interesting and enjoyable.

Dr. Avigdor Zonnenshain

When Dr. Avigdor Zonnenshain first approached me and suggested that we coauthor a book on systems engineering, I was not even familiar with the term. Neither “engineering” nor “systems” sounded like exciting words to me. However, after he had explained what it was all about, I found the subject interesting, special, and innovative.

I had hardly had any previous contact with technological fields. I acquired my basic education in the Faculty of Social Sciences, specializing in “soft” areas, centered on human skills. As a management expert, my professional writing focused on connections between people, human abilities, and the organizational world.

I suddenly discovered that engineers, pure technologists, are beginning to understand that technology does not exist in a vacuum; that it is meant to serve people. In the words of Professor Aviv Rosen, an aeronautical engineer and currently the head of The Gordon Center for Systems Engineering at The Israel Institute of Technology (Technion), which provided the framework for the study this book is based on: “I came from the world of exact science, and I have come to see that in many cases, the ‘soft’ sciences are no less important than the technology itself. There is always a client at the end of the road, and the user’s psychology must be taken into account.”

Commonly attributed to Plato, the proverb “necessity is the mother of invention” is very relevant to systems engineering, a field that emerged from the need to deal with the increasing complexity of technological systems. I have found that methodologies developed in order to cope with technological-systemic constraints can also serve managers, whose very nature is to handle managerial-systemic constraints. One way or the other, the gap between these two worlds, the technological and the human, is closing – everything connects to everything else, as we head toward the formation of supersystems, combining technology and people together.

Indeed, while working on the book, I have found excellent tools that can serve not only the managerial needs of engineering but also all the worlds of management in general. This book is, therefore, a book on management for all intents and purposes. It is intended for managers as well as systems engineers, in equal measure. It has been written in this form, so that managers with no technological background can derive valuable knowledge from it too.

Finally, I wish to express my sincere thanks to my two colleagues, Professor Aviv Rosen and Dr. Avigdor Zonnenshain, who have given me the opportunity to be a part of an exciting process of learning and creation. Besides being first-class professionals, their extensive intellectual abilities are combined with kindness and good-naturedness – a wonderful mix that has made working with them an extraordinary experience.

Shuki Stauber

PREFACE

SYSTEMS ENGINEERING – A DISCIPLINE IN THE MAKING

A discipline in the making, systems engineering connects classical engineering with organizational and managerial systems. It is, therefore, not surprising that one of the main skill sets required of a systems engineer (and its importance increases as the engineer's career progresses) is that of leadership skills. This fact stands in contrast with systems engineering being, at its core, an engineering discipline, practiced by engineers.

In the past, there had been a clearer distinction between professional engineers, skilled in their fields (for instance, electronic engineers, mechanical engineers, or computer engineers) and integration and management people, who brought together the technological systems developed by the engineers. But the ever-accelerating technological developments and globalization created a situation, where this separation delayed processes and compromised the development abilities and, consecutively, competitiveness of those organizations that unconsciously kept sanctifying the distinction between these two overarching areas.

For example, in the past, an engineer could demand to go back and perform countless tests in order to achieve technological perfection. But today, he must take into account such considerations as resource availability and scheduling. *He can no longer act based on "pure" engineering considerations. Being forced to face other, systemic constraints, as well as the "traditional" challenges of his occupation means he must now think like a systems engineer.*

Not all engineers have to undergo this transformation. Many want to continue to focus exclusively on their professional area of expertise. Some, however, wish to use the engineering analysis tools they had acquired (both in their academic studies and

during their work) not only to develop a sophisticated electronic circuit, an advanced machine, or a complex piece of software, but also to “engineer” an entire system that enfolds not only technology, but other components as well, including economic constraints, human factors, and commercial and marketing considerations – these are the systems engineers.

Systems engineers adopt managerial thought patterns, because technology can no longer be kept separate from the wider context it exists in. They gravitate towards systems that rely heavily on technology, where they are best able to utilize their relative advantage: they enhance their managerial thought using the engineering analysis tools they had acquired. This is why so many systems engineers can be found in organizations that develop aircraft or advanced weapon systems, while very few (if any) work for financial institutions or retail networks.

This book attempts to open a window into the world of systems engineers, allowing the readers to learn from the accumulated experience of the people interviewed for the study and perhaps help them adopt new thought patterns and methods of conduct, suitable to each reader’s area of activity. After all, system engineering is, by its very nature, a discipline that traverses the gaps between other disciplines, and so, its methodologies can serve a wide variety of experts from the worlds of management and engineering – from the production manager, wishing to improve his production line; to the medical doctor, developing a new type of syringe; the architect, designing a complex of buildings; and, finally, to the head of a government office, formulating a multiannual plan.

On the structure of this book:

Managing and Engineering Complex Technological Systems is based on a qualitative study that included, at its core, dozens of in-depth interviews with prominent experts in the field. We have conversed with lead systems engineers, high-ranking executives, academic experts, and experienced consultants. Roughly one half of the study’s participants are Israelis, with the other half hailing from a multitude of other countries. We felt it was important to present a wide spectrum of perspectives on this field, as it pertains to the different features of various industries and organizations.

The first part of the book is a general overview of the systems engineering field. It includes its origins and the history of its emergence, its main characteristics, and the directions of its evolution. This overview is based on a series of interviews with the experts and the insights derived from the discussions with them.

Systems engineering grew out of needs that had arisen in complex technological projects, and it maintains a heavy presence in these frameworks to this day. We demonstrate this in the second part of the book, where we discuss two significant Israeli defense system projects. The first is the IAI Lavi project, launched over 30 years ago and never completed; the second is The Iron Dome project, completed successfully and highly acclaimed by the media. The comparison between the conduct of these two projects is very informative, especially when it comes to systems engineering, seeing as, among other things, it illustrates the substantial changes the discipline had undergone during the years that passed between the two projects.

The third, and final, part of the book contains the detailed interviews themselves. It includes rich, detailed information that relies on the knowledge and years of

experience accumulated by the people we met with. These chapters are divided into five sections:

- Systems engineering as the answer to the challenges of a complex technological world – the aerospace industries;
- The development of systems engineering in the commercial and industrial worlds, and in complex civil systems;
- The impact of the accelerated development of the computing world on systems engineering processes;
- Systems engineering and the academic world;
- Systems engineering in the world of training and consulting.

Finally, we would like to thank all the experts who contributed to this book, shared their wisdom and knowledge, and gave us their time. Their names and professional backgrounds are listed in the acknowledgements section, on the next page.

AVIGDOR ZONNENSHAIN
SHUKI STAUBER

LIST OF INTERVIEWEES (ALPHABETICAL ORDER)

AA

Chief Systems Engineer at Rafael Advanced Defense Systems Ltd.

Yossi Ackerman

President and CEO of Elbit Systems Ltd. (1996–2013).

Norman Augustine

President, CEO, and Chairman of the Board of Directors of Lockheed Martin (1987–1997); has since served as the chairman of several presidential and national committees, including US Antarctic Program Blue Ribbon Panel for the assessment of the United States' activities in the South Pole.

Henry Broodney

Head of the Systems Engineering Technologies Group at the IBM Research Lab in Haifa.

Boaz Dovrin

Project manager at Luminis; formerly systems engineer and technical manager at Elbit Systems and Philips Medical Systems.

Sanford (Sandy) Friedenthal

International expert, lecturer, and consultant on model-based systems engineering (MBSE); formerly a Lockheed Martin Fellow.

Dr. Gilead Fortuna

Senior Research Fellow, head of the project “Israel 2028 – Vision and Strategy for Israel” at The Samuel Neaman Institute (since 2009); formerly Senior Vice President at Raphael Advanced Defense Systems Ltd. and Teva Pharmaceutical Industries Ltd.

Alon Gazit

Director of R&D; **Benjamin (Benjie) Rom**, Head of Product Development; **Erez Heisdorf**, Head of Eilat Program – HP Indigo

Dr. Ovadia Harari

Head of the Lavi Project (1980–1988), Vice President of Israel Aircraft Industries Ltd. (until 2006), winner of the Israel Defense Prize for the years 1973 and 1969, winner of The Israel Prize for Technology and Engineering for the year 1987.

Dr. Cecilia Haskins

Associate Professor at the Norwegian University of Science and Technology (NTNU), ESEP, and member of the INCOSE Board of Directors.

Dr. Eric Honour

International expert, consultant, researcher, and teacher of systems engineering.

Prof. Joseph Kasser

International expert, lecturer, and researcher on systems engineering; currently, a visiting professor at the National University of Singapore (NUS).

Harold (Bud) Lawson

International expert, researcher, lecturer, and consultant on Systems Thinking, Systems Engineering, and Software Engineering; Professor Emeritus of telecommunications and computer systems at the Linköping University, Sweden.

Niels Malotaux

International consultant, specializing in helping projects and organizations.

Dr. Jacob (Kobi) Reiner

Chief Systems Engineer at Rafael Advanced Defense Systems Ltd.

Prof. Aviv Rosen

Faculty member at The Faculty of Aerospace Engineering at Israel Institute of Technology (Technion), initiator and current head of the Technion’s Systems Engineering ME program, also, currently, the head of The Technion’s Gordon Center for Systems Engineering.