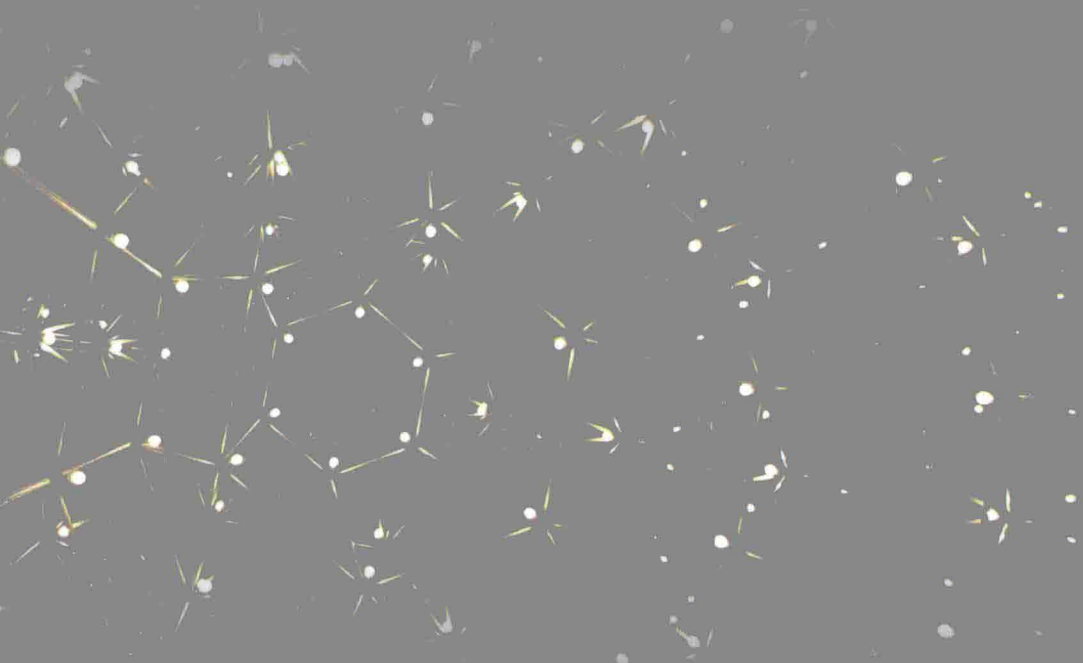
Wiley Series in Systems Engineering and Management
Andrew P. Sage, Series Editor

RELIABILITY, MAINTAINABILITY, AND SUPPORTABILITY

Best Practices for Systems Engineers

MICHAEL TORTORELLA



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For Matthew
1982–1999
Lux æterna

Foreword

PURPOSE AND RATIONALE

Students and professionals have many choices of text and reference books for the sustainability engineering disciplines: reliability, maintainability, and supportability. Available books range from theoretical treatises on the mathematical theory of reliability, applied maintainability and logistics modeling, studies in reliability physics, and books devoted to systems management. But there's still something missing: there is a need for an exposition of the sustainability engineering activities that systems engineers need to carry out, which explains the purposes and benefits of the activities without necessarily explaining how to do them all in detail. This book fills that need.

Several decades of experience in sustainability engineering and management in the telecommunications industry and additional experience in research and teaching have led me to these relevant observations.

1. Few publications in the sustainability disciplines focus on the core systems engineering tasks of creating, managing, and tracking requirements for these disciplines specifically.
2. The small number of degree-granting programs in sustainability engineering means that many systems engineers have no exposure to these ideas until they are assigned to deal with them in the work environment.
3. The gap between what is known and available in the research literature and what is routinely practiced in day-to-day sustainability engineering is large and growing. Many sustainability engineers use oversimplified models and tools to deal with sustainability engineering tasks and consequently miss opportunities to develop more thorough and informative product management and improvement plans at lower cost.
4. Systems engineers, in particular, because of the broad scope of their responsibilities, need support from those with specialized expertise to write good sustainability requirements, understand the results provided

to them by sustainability engineering specialists, and track compliance with stated sustainability requirements. Consequently, they need enough background knowledge in these areas to be good suppliers and customers for the specialist teams.

5. Many software tools essential for executing complex sustainability engineering tasks often (silently) incorporate simplifying assumptions, rely on the user to discern when results are reasonable or not, and do not give the user good insight into what to expect from the tool and what not to expect from the tool.

Sustainability engineering and management is not an obscure, arcane branch of knowledge. It is a human endeavor that can readily be carried out systematically and on the basis of a manageable number of principles. The purpose of this book is to provide that basis for systems engineers in particular. Certainly, few have as much influence on a product's design as do systems engineers. The creation of appropriate sustainability requirements is a key step to developing a system whose realized reliability, maintainability, and supportability meet the needs and desires of the system's customers while promoting success and profit to the vendor. Conversely, incomplete, unfocused, or inappropriate requirements lead to customer dissatisfaction with the system they purchase and use and cost the vendor more in warranty costs, maintenance of an extensive repair business, and lost goodwill. Our purpose here is to provide systems engineers with the principles and tools needed to craft sustainability requirements that make the product or system successful in satisfying the customers' needs and desires for reliability, maintainability, and supportability while keeping costs manageable. Our purpose is also to provide methods and tools systems engineers can use to determine whether sustainability requirements are being met satisfactorily by understanding and analysis of data from field installations. Finally, the book discusses enough quantitative modeling for reliability, maintainability, and supportability to support systems engineers in their engineering, management, validation, and communication tasks.

It is important to note that this book is not intended as a textbook in the mathematical theory of reliability (or the mathematical underpinnings of maintainability or supportability). Rather, our intention is to provide systems engineers with knowledge about the results of these theories so that, while they may sometimes construct needed reliability, maintainability, and supportability models on their own, it is more important that they be able to successfully acquire and use information provided to them by specialist engineers in these disciplines. The customer–supplier model provides a useful context for this interaction:

- Systems engineers act as suppliers in providing specialist engineers with clear and effective reliability, maintainability, and supportability requirements for the product.
- Systems engineers act as customers for the reliability, maintainability, and supportability models, data analysis, and so on, provided by specialist engineering teams during development.

Therefore, systems engineers need a good grasp of the language and concepts used in these areas, while not necessarily needing to be able to carry out extensive modeling or data analysis themselves. While this book is careful to describe the necessary language and concepts correctly and in appropriate contexts, it makes no attempt to provide mathematical proofs for the results cited. References are provided for those interested in pursuing details of the mathematical theory of reliability, but those details are not within the scope or purpose of this book.

GOALS

I hope this book will enable systems engineers to lead the development of systems (which we will interpret broadly in this book as encompassing products and services) whose reliability, maintainability, and supportability meet and exceed the expectations of their customers and provide success and profit to their employers. My intention is that systems engineers will themselves be able to employ, and encourage their sustainability engineering specialists to employ, the best practices discussed here in an orderly, systematic fashion guided by customer needs. I recognize that systems engineers have a very broad range of responsibilities, and it may not be possible for them to deal with every responsibility at equal depth. Therefore, it is important that their sustainability engineering and management responsibilities be supported by as straightforward and systematic a program as possible. I emphasize the thought processes underlying all the activities a systems engineer may have to undertake to ensure successful product or system sustainability. To avoid losing sight of the forest for the trees, we repeatedly return to the basic questions and first principles of the field in all the applications we cover, including hardware products, software-intensive systems, services, and high-consequence systems. My intention in doing this is to help systems engineers choose appropriate methods and tools to accomplish their purposes, and thereby create the most suitable sustainability requirements consistent with fulfilling customer needs and expectations and supplier success.

ORGANIZATION OF THIS BOOK

Every author likes to think that he brings to the reader a uniquely formative experience through the superior organization of topics and methods in his book. If only it were that simple. Success in learning depends primarily on student commitment. I can only try to make that job easier. I hope that the devices I use in this book will fulfill that wish.

- The book is organized into three major divisions, one corresponding to each of reliability, maintainability, and supportability engineering. Within each division, there is material on
  - Requirements development,
  - Quantitative modeling sufficient for understanding, developing, and interpreting requirements,
  - Statistical analysis for checking whether systems in operation meet or do not meet requirements, and
  - Best practices in each of these areas.
- I place a lot of emphasis on correct use of language. As discussed at length in Chapter 1, the language we use in the formal system that constitutes sustainability engineering contains many of the same words we use in ordinary discourse. It is vital to keep in mind which context you are operating in at all times. To help you do this in places where I think there is more than the usual possibility for confusion, I will point out in the text information you need to dispel that confusion. These instances are introduced by the header "Language tip" and they appear in many places in the text.
- This book is primarily for systems engineers whose main concern is the determination and development of appropriate requirements so that designers may fulfill the intent of the customer. Accordingly, the book emphasizes the use of various sustainability engineering methods and techniques in crafting requirements that are
  - Focused on the customers' needs,
  - Unambiguous,
  - Easily understood by the requirements' stakeholders (customers, designers, and management), and
  - Verifiable through collection and analysis of data from system operation.

  The device employed in the book to promote this goal is the frequent interjection of "Requirements tips" that appear when needed and of most benefit.
- An equally important concern of systems engineers is determining when requirements are being met by systems operating in customer environments. Accordingly, a chapter or section in each of the major divisions of the book is devoted to the statistical analyses needed to accomplish this task.
- The title of the book emphasizes "Best Practices." Each chapter concludes with a section summarizing the current best practices for systems engineers concerning the material covered in the chapter.
- Finally, I believe that everything we do is a process, whether we call it that or not. In particular, we should all be mindful that everything we do can be improved. Requirements development and verification are no exception (indeed, this book is no exception, and I welcome suggestions from readers to help make the next version better).

Acknowledgments

I have had the good fortune to work with many talented and caring people who have shared their knowledge and helped shape my thinking in this area. First and foremost, I want to thank the late Norman A. Marlow who gave me the freedom to pursue interesting and important problems in network and service reliability and guided my early career at Bell Laboratories. Elsayed A. Elsayed and Endre Boros promoted my pleasant and fruitful relationship with Rutgers University. Many other colleagues and friends contributed their time and expertise to help me learn more about reliability engineering. These include Susan Albin, Sigmund J. Amster, Lawrence A. Baxter, Michele Boulanger, Chun Kin Chan, Ramon V. Leon, Michael LuValle, and William Q. Meeker. José Ramirez-Marquez helped me pass the torch. Working with Bill Frakes on the SUPER project was an education and a pleasure. A. Blanton Godfrey, Jeffrey H. Hooper, and William V. Robinson provided invaluable management support, and Jon Bankert and Jack Sipress gave me an opportunity to work with the Bell Labs Undersea Cable Laboratory where I learned a great deal of practical reliability engineering. I am grateful to Stevens Institute of Technology for employing me to teach a course in the Systems Engineering program based on these ideas. I am deeply grateful to Chun Kin Chan, Bill Frakes, and D. A. Hoeflin for carefully reading the manuscript and offering excellent suggestions. I have also benefitted from conversations with David Coit, Elsayed Elsayed, Shirish Kher, Mohcene Mezhoudi, Himanshu Pant, William V. Robinson, and Terry Welsher. Outside my immediate circle of colleagues, I thank Harry Ascher, Alessandro Birolini, Ilya Gertsbakh, and William A. Thompson. Learning from their clear and well-constructed books helped me be a better reliability engineer. Laura Madison helped clean up my sometimes too-convoluted prose; her patience in taking on a bigger job than she anticipated is much appreciated. Finally, my thanks to Andrea for her

patience with my frequent and extended disappearances into the authorial vortex. To all these and many more too numerous to mention, thank you for helping shape this book. I have tried to learn from your suggestions, but people tell me I am sometimes a stubborn cuss, so there may remain errors in the book, and if so, they are mine alone.

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