ANALYSES FOR DURABILITY AND SYSTEM DESIGN LIFETIME

An important issue in engineering design is a system's design lifetime. Economists study durability choice problems for consumer goods, but seldom address lifetime problem(s) of complex engineering systems. The issues for engineering systems are complex and multidisciplinary and require an understanding of the "technicalities of durability" and the economic implications of the marginal cost of durability and of value maximization. Commonly the design lifetime for infrastructure is set between 30 and 70 years, with limited rationale. Satellite lifetimes are also assigned with limited analysis. This book provides a systemic qualitative and quantitative approach to these problems, addressing first the technicality of durability, second the marginal cost of durability, and third the durability choice problem for complex engineering systems with network externalities (competition and market uncertainty) and obsolescence effects (technology evolution). Because the analyses are system-specific, a satellite example is used to illustrate the essence and provide a quantitative application of these analyses.

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Analyses for Durability and System Design Lifetime

A MULTIDISCIPLINARY APPROACH

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To Carl, Mia, Jihad, Abu Ali, Na'ama, and Michal

That they may find fulfillment in a peaceful, diversely rich, and prosperous Middle East

To The Reader

I know that, despite my care, nothing will be easier than to criticize this work if anyone ever thinks of criticizing it. I think those who want to regard it closely will find, in the entire work, a mother thought that so to speak links all its parts. But the diversity of the objects I had to treat is very great, and whoever undertakes to oppose an isolated fact to the sum of facts I cite or a detached idea to the sum of ideas will succeed without difficulty. I should therefore wish that one do me a favor of reading me in the same spirit that presided over my work, and that one judges this work by the general impression it leaves, just as I myself decided, not by such and such a reason, but by the mass of reasons.

Alexis de Tocqueville, *Democracy in America*, 1835

Contents

Preface *page* xi

1 Introduction: On Time 1

1.1 Sundials and human time 1
1.2 Time and human artifacts 5
1.3 Two broad categories of questions regarding durability 5
1.4 Why the interest in product durability and system design lifetime? 8
1.5 Book organization 10

2 To Reduce or to Extend Durability? A Qualitative Discussion of Issues at Stake 14

2.1 Introduction 14
2.2 Nomenclature: Durability and design lifetime – A matter of connotation 15
2.3 To reduce or to extend a product's durability? What is at stake and for whom? 16
2.4 Example: To reduce or to extend a spacecraft's design lifetime? 22

3 A Brief History of Economic Thought on Durability 24

3.1 Introduction: Snapshot from the middle of the story 24
3.2 Periodization and the history of economic thought on durability 26
3.3 The origins and preanalytic period in the history of economic thought on durability: Knut Wicksell and Edward Chamberlin 27
3.4 Growing interest in durability: Limitations of the price–quantity analysis and suspicious industry practices 28

3.5 "Flawed analytic" period in the history of economic thought on durability 32
3.6 The Swan-centric period in the history of economic thought on durability 33
3.7 The identification of the time inconsistency problem for durable goods monopolists 35
3.8 Recent economic literature on durability 41
3.9 Limitations of current economic thinking about durability 44
3.10 Conclusions 48
Appendix – Origins of Coase's contribution to the time inconsistency problem of durable goods monopolists 49

4 Analysis of Marginal Cost of Durability and System Cost per Day 53

4.1 Introduction 53
4.2 Nomenclature: Durability, design lifetime, and service life 54
4.3 On values, metrics, and tradeoffs in the search for optimal durability 56
4.4 Scaling effects and marginal cost of durability: The example of a satellite 61
4.5 Cost elasticity of durability 71
4.6 From marginal cost of durability to cost per day: Regions and archetypes 74
4.7 Conclusions 78

5 Flawed Metrics: System Cost per Day and Cost per Payload 81

5.1 Introduction 82
5.2 Two metrics in space system design and their implications 83
5.3 Investigating satellite cost per day 85
5.4 The case for a value-centric mindset in system design 87
5.5 Satellite cost per transponder: Design implications and limitations 94
5.6 Conclusions 97

6 Durability Choice and Optimal Design Lifetime for Complex Engineering Systems 101

6.1 Introduction: A topic overlooked by economists and engineers 101
6.2 An augmented perspective on design and optimization: A system's value and the associated flow of service 102

6.3 Optimal durability under steady-state and deterministic assumptions 104
6.4 Durability, depreciation, and obsolescence: A preliminary account 110
6.5 Uncertainty, risk, and the durability choice problem: A preliminary account 118
6.6 Conclusions 123

EPILOGUE. Perspectives in Design: The Deacon's Masterpiece and Hundred-Year Aircraft, Spacecraft, and Other Complex Engineering Systems 128

1. On durability through robustness: The Oliver Wendell Holmes way 129
2. Time to failure 131
3. Beyond robustness: On durability through flexibility in system design 136
4. The new deacon's masterpiece: Challenge for poets and engineers! 141

APPENDIX A. Beyond Cost Models, System Utility or Revenue Models: Example of a Communications Satellite 145

A.1 Introduction 145
A.2 Motivation: Proliferation of system cost models and absence of revenue or utility models 146
A.3 Developing the revenue model structure for a communications satellite 149
A.4 Modeling satellite loading dynamics 153
A.5 Integrating satellite loading dynamics with transponder lease price 164
A.6 Conclusions 169

APPENDIX B. On Durability and Economic Depreciation 171

B.1 Introduction 171
B.2 Depreciation, deterioration, and obsolescence: The traditional interpretation 174
B.3 The model 175
B.4 Depreciation and incremental present value 178
B.5 Depreciation and obsolescence 188
B.6 Concluding remarks 191

Index 195

Preface

Time and the ephemeral nature of human life have been major themes for poets, philosophers, and theologians. Every scripture, philosophical writing, and work of art addresses, explicitly or implicitly, issues of time and the human experience of it.

Engineers have also considered and often grapple with issues of time, except that, instead of the human experience of it, they deal with the relationship of engineering artifacts with time. Less profound than the previous subject but equally thought-provoking is the transiency, not only of human life, but also of human artifacts. Through structural or functional degradation, or loss of economic relevance, the hand of time lies heavy on engineering designs. Several terms are used to describe this particular aspect of a product or a system's relationship with time, namely the duration from fielding a system, that is, when it first enters operation, to its final breakdown or retirement. These terms include *lifespan*, *service life*, *durability*, and *design lifetime*, to name a few. This book discusses these issues in the context of complex engineering systems.

More specifically, this book explores an important issue in engineering design that is becoming increasingly critical for complex engineering systems in general, and aerospace systems in particular, namely the selection and implications of a system's design lifetime. Although economists have grappled with the durability choice problem for simple consumer goods, limited attention has been given to the design lifetime problem(s) of complex engineering systems. The issues at stake in selecting a reduced or an extended design lifetime for an engineering system are complex and multidisciplinary in nature; they require a thorough engineering understanding

of the "technicalities of durability" along with the economic implications of the marginal cost of durability and of the value maximization problem in guiding the durability choice problem.

Systems engineers and program managers recognize the increasing importance of the durability choice problem for engineering systems. For example, design lifetime for infrastructure is typically set at 30–70 years, often with limited rationale, and satellite lifetimes are assigned rather arbitrarily or with limited quantitative analysis (cost-based). This book provides a systemic qualitative and quantitative approach to these problems in the form of a triptych addressing, first, the technicalities of durability; second, the marginal cost of durability, along with the economies of scale (in the time dimension), if any, that result from extended durability; and third, the durability choice problem for complex engineering systems in the face of network externalities (competition and market uncertainty) and obsolescence effects (technology evolution). Because the details of the analyses are system-specific, a satellite example is used in several chapters to illustrate the essence and provide a quantitative application of these analyses.

Also addressed is the increasing tension between the design lifetimes of present-day complex engineering systems and the shortening time scales associated with the obsolescence of their underlying technology base. The book ends with a discussion of the need for and growing interest in the concept of flexibility in system design.

The book is intended for graduate students, researchers, and practitioners. Each chapter is self-contained and can be read independent of the other chapters. The six chapters and Epilogue do, however, tell a coherent story that reaches its climax in Chapters 5 and 6, where traditional engineering wisdom and the "economies of scale" argument in system design are challenged and proved flawed under certain environmental conditions; an alternative framework and solutions are provided in Chapter 6.

Finally, it should be noted that this text is but a small book about a broad topic. It does not pretend to be exhaustive in its treatment of durability related issues. Important topics such as product replacement and recycling, for example, have not been addressed. These topics reflect "downstream" issues that define the end of life, or post-service life, of a system, whereas this book deals with the "upstream" problem of the definition and selection of

the intended design lifetime of the system. More specialized texts would do better justice to these subjects of product replacement and recycling than a summary treatment in the present work.

This book is one "panel" of a triptych that consists of two additional books (forthcoming) on flexibility and uncertainty in engineering design. The close connection among time (durability), uncertainty, and flexibility is elaborated in the Epilogue of the present work.