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Dong-Ping Song

Optimal Control and Optimization of Stochastic Supply Chain Systems

Springer

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To my wife, Li Jin, and my son, Tianyi

Series Editors' Foreword

The series *Advances in Industrial Control* aims to report and encourage technology transfer in control engineering. The rapid development of control technology has an impact on all areas of the control discipline: new theory, new controllers, actuators, sensors, new industrial processes, computer methods, new applications, new philosophies, and new challenges. Much of this development work resides in industrial reports, feasibility study papers, and the reports of advanced collaborative projects. The series offers an opportunity for researchers to present an extended exposition of such new work in all aspects of industrial control for wider and rapid dissemination.

For many readers from the control community, the notion of a "supply chain" probably conjures up the advanced information technologies used for the demand and supply of goods and products for commercial enterprises such as retail and supermarket chains. However, as society infrastructure becomes ever larger and more complex, supply chains exist across a wide variety of industrial and commercial activities. For example, effective supply chains are important in bringing together the components in aircraft manufacture and in automobile production lines.

Common features of a supply chain include a focal "consumer" point at the top of a supply chain that is issuing "orders" or demands for finished goods and processed materials. These demands create information flows down to the suppliers (manufacturers) who in turn attempt to meet these demands and transport the required goods and products along the chain to the consuming focal point. Thus, supply chains have an information–material flow duality. In many supply chains, the suppliers themselves are also a link in a supply chain of their own, so it is easily seen how the structure of a supply chain can quickly become very complex. Other complicating factors might be "competition" between the supplier vendors at various points of the supply chain or, alternatively, policies where the activities in the whole supply chain are coordinated or integrated using cooperation strategies to try to make efficiency gains.

Another aspect of the supply chain field is the "people and organization" dimension that does not usually exist in more conventional engineering process or industrial control system studies. Consequently, there is an extensive literature

on "business management" approaches and philosophies for the operation of an efficient, reliable, and cost-effective supply chain. To enhance and improve supply chain performance, there are also a number of professional organizations and institutes that provide training and other services to supply chain operatives and company personnel.

Given the importance of the field, the editors of the *Advances in Industrial Control* monograph series welcome this very first monograph in the series on supply chain control. Professor Dong-Ping Song's monograph *Optimal Control and Optimization of Stochastic Supply Chain Systems* studies these systems using an analytical framework and the techniques of control systems including system modeling, optimal control derivation, system simulation, and the formulation of the best suboptimal control solutions. Supply chains rapidly become very complex, and Prof. Song's monograph reports work that is focused on bridging the gap between modeling complexity and solution simplicity in stochastic supply chains. The control solutions presented use optimal control methods, and these are investigated and explored to indicate what can be learnt from the structure of these optimal policies. Subsequently, Prof. Song derives easy-to-implement suboptimal solution policies and reports on solutions for situations with multiple inventory and production decisions in supply chain systems in the presence of uncertainty and stochastic effects. Overall, the aim is to emphasize the global integration of the supply chain rather than hierarchical decision-making.

Other entries in the *Advances in Industrial Control* series that have some relation to the supply chain topic include:

1. Palit, A.K., Popovic, D.: Computational Intelligence in Time Series Forecasting. (2005). ISBN 978-1-85233-948-7
2. Bogdan, S., Lewis, F.L., Kovacic, Z., Mireles, J.: Manufacturing Systems Control Design. (2006). ISBN 978-1-85233-982-1

Professor Song's monograph makes an invaluable addition to this small subset of monographs on these important enterprise and manufacturing subjects.

Industrial Control Centre M.J. Grimble
Glasgow, Scotland, UK M.A. Johnson

Preface

Subject of the Book

In the last two decades, supply chain systems have attracted a huge amount of attention from both the industrial and academic communities. Leading companies now see their supply chains as an important source to gain competitive advantages. The success of Wal-Mart in 1990s was partly attributed to the application of innovative supply chain management strategies, for example, the continuous replenishment program or the vendor-managed inventory strategy which coordinates the inventory management across the retailer and its suppliers. Business organizations are increasingly recognizing the importance of breaking down the barriers between functions and entities and tend to control and optimize their supply chains as an integrated system.

Although many companies have been involved in the analysis of their supply chain systems to seek performance improvement, in most cases, this analysis is performed based on experience and intuition. Very few analytical models have been used in this process (Simchi-Levi et al. 2009). This gap may be explained from two perspectives. The first perspective is the difficulty in obtaining solutions from the analytical models. Supply chain management emphasizes the integration and optimization of the entire supply chain system. A number of factors contribute to the complexity of modeling supply chain systems. Firstly, a supply chain may involve different functions and entities, a number of tasks and resources, and many different types of decisions. Secondly, supply chain components interact with each other in a variety of relationship formats. Such relationships influence the level of information flow, the degree of uncertainty, and the responsibility of decision-making. The modeling and solution are therefore usually problem dependent. Thirdly, supply chain systems are dynamic and subject to various uncertainties, which may exist in external environment and in internal activities. As a stochastic system, it is not guaranteed that the system will be stable if not well designed or controlled. The complexity of the supply chain systems obviously makes analytical tools difficult to solve many supply chain management problems.

The second perspective is the difficulty in implementing the solutions in practice. The solutions from analytical models, even if they exist, are often not robust and flexible enough to allow industry to use them effectively. From an industrial perspective, the operationability and simplicity of control policies are vital to their successful implementation and execution. Therefore, there is a need to bridge the gap between the complexity of the models due to the requirement of optimization and the simplicity of the solutions due to the requirement of implementation.

In this book, we intend to fill this gap by formulating analytical models for various typical stochastic supply chain systems, investigating the structural characteristics of the optimal control policies, constructing easy-to-operate suboptimal policies, establishing the system stability conditions, and addressing the optimization of suboptimal policies.

How the Book Is Structured

Chapter 1 provides a general introduction to stochastic supply chain systems. Various types of uncertainties in supply chain systems and different channel relationships between supply chain entities are discussed. The manufacturer is regarded as a focal company in the supply chain. The aim of this book is to tackle the optimal control and optimization problem for stochastic supply chain systems. More specifically, the main objective is to seek the optimal production control policies and the optimal ordering policies in the supply chain by taking into account a variety of uncertainties such as random customer demands, stochastic processing times, unreliable machines, and stochastic material lead times. The basic assumptions are stated, and the structure of the book is outlined.

In Chaps. 2, 3, 4, 5, 6, and 7, several typical stochastic supply chain systems will be studied. Analytical models are formulated and analyzed in detail. The purpose is to investigate and establish the structural characteristics of the optimal policies.

In Chaps. 8, 9, 10, 11, and 12, the structural knowledge of the optimal control policies obtained in earlier chapters will be utilized to construct easy-to-operate suboptimal control policies for various stochastic supply chain systems accordingly. Here the focus is to achieve the trade-off between the closeness to the optimality of the constructed policies and the degree of simplicity in terms of their implementation. Extensive numerical examples are provided to demonstrate the effectiveness of the proposed threshold-type policies. In addition, the system stability issues will also be addressed, which is essential when steady-state performance measures are concerned.

In Chaps. 13, 14, and 15, the optimization of threshold-type control policies and their robustness are addressed. The value iteration-based method and the stationary distribution-based method are first introduced to optimize the threshold parameters. Then, simulation-based optimization methods including genetic algorithm,

simulated annealing, and ordinal optimization are presented. A range of numerical examples are given to demonstrate their efficiency. Finally, the main conclusions and limitations are summarized, and further research directions are discussed.

Reference

Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E.: Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies, 3rd edn. McGraw-Hill, Irwin (2009)

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Contents

1 Stochastic Supply Chain Systems 1
1.1 Introduction 1
1.2 Uncertainties in Supply Chain Systems 3
1.3 Channel Relationships in Supply Chain Systems 3
1.4 Optimal Control and Optimization in Stochastic Supply Chains .. 5
1.5 Structure of the Book 6
References 8

2 Optimal Control of Basic Integrated Supply Chains 11
2.1 Introduction 11
2.2 Problem Formulation 12
2.3 Optimal Control Policy 16
2.4 Structural Properties of the Value Function 18
2.5 Characterization of Optimal Policy 23
2.6 Discussions 27
2.6.1 Interpretation and Extension 27
2.6.2 Information Sharing 28
2.6.3 Channel Coordination 29
2.6.4 Cost and Benefit Sharing 31
2.7 Notes 32
References 33

3 Optimal Control of Supply Chains in More General Situations 37
3.1 Introduction 37
3.2 One Outstanding Order with Its Size Not Changeable Once Issued 38
3.3 Two Outstanding Orders with Their Sizes Not Changeable Once Issued 41
3.4 One Outstanding Order with Its Size Not Changeable and Its Lead Time Following an Erlang Distribution 44

3.5 Numerical Examples 46
3.6 Multistage Serial Supply Chain Systems 48
3.7 Discussions and Notes 51
3.7.1 Deterministic Lead Times and Random Demands 51
3.7.2 Stochastic Lead Times and Outstanding Orders 53
3.7.3 Multiple Replenishment Channels and Order Information 55
3.7.4 Ordering Capacity and Storage Capacity 56
References 57

4 Optimal Control of Supply Chain Systems with Backordering Decisions 61
4.1 Introduction 61
4.2 Optimal Control in a Supply Chain with Backordering Decisions. 62
4.3 Optimal Control in a Failure-Prone Manufacturing Supply Chain with Backordering Decisions 67
4.3.1 Problem Formulation 67
4.3.2 Optimal Control Policy 70
4.3.3 Characterization of the Optimal Policy 71
4.4 Discussions and Notes 74
4.4.1 Backordering Decisions 74
4.4.2 Failure-Prone Manufacturing Supply Chains 75
References 76

5 Optimal Control of Supply Chain Systems with Preventive Maintenance Decisions 79
5.1 Introduction 79
5.2 Optimal Control of Ordering, Production, and Preventive Maintenance in a Supply Chain 80
5.2.1 Optimal Control Under Operation-Dependent Failures... 81
5.2.2 Optimal Control Under Time-Dependent Failures 86
5.3 Optimal Control of Production and Preventive Maintenance in a Failure-Prone Manufacturing Supply Chain 87
5.4 Discussion and Notes 90
References 93

6 Optimal Control of Supply Chain Systems with Assembly Operation 95
6.1 Introduction 95
6.2 Problem Formulation 96
6.3 Optimal Control Policy 98
6.4 Optimal Control Policy with Maximum Order Size One 99
6.4.1 Structural Properties of Optimal Value Function 100
6.4.2 Characterization of the Optimal Policy 103
6.5 The Failure-Prone Assembly Supply Chain 106
6.6 Discussion and Notes 108
References 109

7 Optimal Control of Supply Chain Systems with Multiple Products .. 111
7.1 Introduction 111
7.2 Optimal Ordering and Production Control in a Supply Chain with Multiple Products 112
7.3 Optimal Production Rate Allocation in a Failure-Prone Manufacturing Supply Chain Producing Two Part-Types 115
7.3.1 Structural Properties of the Optimal Value Function 117
7.3.2 Characterization of the Optimal Policy 122
7.4 Discussion and Notes 125
References 128

8 Threshold-Type Control Policies and System Stability for Serial Supply Chain Systems 131
8.1 Introduction 131
8.2 Stability Conditions and the Long-Run Average Cost Case 132
8.3 Threshold Control Policies in the Basic Supply Chain System 135
8.4 Threshold Control Policies in More General Supply Chain Systems 142
8.4.1 Supply Chain Systems Subject to One Non-changeable Outstanding Order 142
8.4.2 Supply Chain Systems with Two Parallel Outstanding Orders 143
8.4.3 Supply Chain Systems Subject to Erlang Distributed Lead Times 143
8.4.4 Numerical Examples in More General Supply Chain Systems 144
8.5 Threshold Control Policy for Multistage Serial Supply Chains 145
8.6 Discussion and Notes 146
References 147

9 Threshold-Type Control of Supply Chain Systems with Backordering Decisions 149
9.1 Introduction 149
9.2 Threshold Control in the Basic Serial Supply Chain with Backordering Decisions 149
9.3 Threshold Control in a Failure-Prone Manufacturing Supply Chain with Backordering Decisions 153
9.3.1 System Stability and the Long-Run Average Cost 153
9.3.2 Stationary Distribution 155
9.3.3 Steady-State Performance Measures 158
9.3.4 Numerical Examples 159
9.4 Notes 160
References 160

10 Threshold-Type Control of Supply Chain Systems with Preventive Maintenance Decisions 163
10.1 System Stability 163
10.2 Threshold-Type Control for Ordering, Production, and Preventive Maintenance in a Supply Chain 164
10.3 Threshold-Type Control for Production and Preventive Maintenance in a Manufacturing Supply Chain Without Raw Material Ordering Activity 167
10.3.1 State Transition Map Under Type-One Threshold Policy 168
10.3.2 Stationary Distribution Under Type-One Threshold Policy 168
10.3.3 Steady-State Performance Measures 174
10.3.4 Numerical Examples 177
10.4 Notes 182
References 183

11 Threshold-Type Control of Supply Chain Systems with Assembly Operations 185
11.1 System Stability 185
11.2 Threshold Control Policies for Reliable Assembly Supply Chains 186
11.2.1 Illustration of the Switching Structure of the Optimal Policy 186
11.2.2 Threshold Control Policies 188
11.2.3 Effectiveness of Threshold Control Policies 191
11.3 Threshold Control Policies for Failure-Prone Assembly Supply Chains 192
11.3.1 Illustration of the Switching Structure of the Optimal Policy 192
11.3.2 Threshold Control Policies 195
11.3.3 Effectiveness of Threshold Control Policies 196
11.4 Notes 197
References 199

12 Threshold-Type Control of Supply Chain Systems with Multiple Products 201
12.1 System Stability 201
12.2 Threshold-Type Control for Ordering and Production in a Supply Chain with Multiple Products 202
12.3 Threshold-Type Control for Production Rate Allocation in a Failure-Prone Manufacturing Supply Chain with Two Part-Types 205
12.4 Prioritized Base-Stock Threshold Control for a Manufacturing Supply Chain Producing Two Part-Types with Given Priority 209
12.4.1 System Stability 209

12.4.2 Stationary Distribution 212
12.4.3 Steady-State Performance Measures..... 216
12.4.4 Optimal Base-Stock Levels 217
12.4.5 Numerical Examples 221
12.5 Discussion and Notes 222
References..... 223

13 Optimization of Threshold Control Parameters via Numerical Methods 225
13.1 Introduction..... 225
13.2 Optimization of Threshold Parameters in Discounted-Cost Situations 226
13.2.1 Optimization of Threshold Values via Value Iteration Method 227
13.2.2 Application and Computational Performance 227
13.3 Optimization of Threshold Parameters in Long-Run Average Cost Situations..... 230
13.3.1 Optimization of Threshold Parameters via Value Iteration Method 231
13.3.2 Optimization of Threshold Parameters via Stationary Distribution 231
13.3.3 Application and Computational Performance 232
13.4 Robustness of Threshold-Type Control Policies 234
13.5 Discussion and Notes 235
References..... 238

14 Optimization of Threshold Control Parameters via Simulation-Based Methods..... 241
14.1 Introduction..... 241
14.2 Performance Evaluation Through an Event-Driven Simulation Model 242
14.3 Simulation-Based Optimization Methods..... 244
14.3.1 Genetic Algorithms (Evolutionary Strategy) 245
14.3.2 Simulated Annealing 248
14.3.3 Numerical Examples 251
14.4 Ordinal Optimization Technique 253
14.4.1 The Concept of Ordinal Optimization 253
14.4.2 An OO-Based Elite GA 254
14.5 Notes..... 256
References..... 258

15 Conclusions..... 261
15.1 Conclusions and Managerial Insights 261
15.2 Limitations and Further Research 263
References..... 265

Index..... 267