

FACULTY OF ENGINEERING AND INFORMATION
TECHNOLOGY

Multilevel Decision Making for Supply Chain Management

Jialin Han

A thesis submitted for the Degree of

Doctor of Philosophy



University of Technology Sydney

February, 2016

CERTIFICATE OF AUTHORSHIP/ORIGINALITY

This thesis is the result of a research candidature conducted jointly with another University as part of a collaborative Doctoral degree. I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as part of the collaborative doctoral degree and/or fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

ACKNOWLEDGEMENTS

I wish to express my deep and sincere gratitude to my supervisors, Professor Jie Lu and Professor Guangquan Zhang. It has been a great gift and pleasure to be their student. Their comprehensive guidance has covered all aspects of my PhD study, including research topic selection, research methodology and academic writing skills. Their critical comments and suggestions have strengthened my study significantly. Their respective rigorous academic skills and excellent work ethic have been an inspiration over the course of my PhD study and I will draw upon the example they have set throughout my future research career. Without their high order supervision and continuous encouragement, this research could not have been completed on time. Moreover, they have also kindly provided me with sincere help and advice when I have sought it.

I am grateful to all members of the Decision Systems and e-Service Intelligent (DeSI) Lab in the Center for Quantum Computation and Intelligent Systems (QCIS) for their careful participation in my presentation and valuable comments for my research. I would like also to thank Ms. Sue Felix and Dr. Shale Preston for helping me to correct English presentation problems in my publications and this thesis.

I wish to express my appreciation for the financial support I received for my study. Special thanks go to the China Scholarship Council (CSC) and the University of Technology Sydney (UTS).

Last but not least, I would like to express my heartfelt appreciation to my family. Thanks to my mother and father for their continuous encouragement and generous support.

ABSTRACT

Multilevel decision-making techniques aim to handle decentralized decision problems that feature multiple decision entities distributed throughout a hierarchical organization. Decision entities at the upper level and the lower level are respectively termed the *leader* and the *follower*. Three challenges have appeared in the current developments in multilevel decision-making: (1) large-scale - multilevel decision problems become large-scale owing to high-dimensional decision variables; (2) uncertainty - uncertain information makes related decision parameters and conditions imprecisely or ambiguously known to decision entities; (3) diversification - multiple decision entities that have a variety of relationships with one another may exist at each decision level. However, existing decision models or solution approaches cannot completely and effectively handle these large-scale, uncertain and diversified multilevel decision problems.

To overcome these three challenges, this thesis addresses theoretical techniques for handling three categories of unsolved multilevel decision problems and applies the proposed techniques to deal with real-world problems in supply chain management (SCM). First, the thesis presents a heuristics-based particle swarm optimization (PSO) algorithm for solving large-scale nonlinear bi-level decision problems and then extends the bi-level PSO algorithm to solve tri-level decision problems. Second, based on a commonly used fuzzy number ranking method, the thesis develops a compromise-based PSO algorithm for solving fuzzy nonlinear bi-level decision problems. Third, to handle tri-level decision problems with multiple followers at the middle and bottom levels, the thesis provides different tri-level multi-follower (TLMF) decision models to describe various relationships between multiple followers and

develops a TLMF *K*th-Best algorithm; moreover, an evaluation method based on fuzzy programming is proposed to assess the satisfaction of decision entities towards the obtained solution. Lastly, these proposed multilevel decision-making techniques are applied to handle decentralized production and inventory operational problems in SCM.

TABLE OF CONTENTS

CERTIFICATE OF AUTHORSHIP/ORIGINALITY	i
ACKNOWLEDGEMENTS	ii
ABSTRACT	iii
TABLE OF CONTENTS.....	v
LIST OF FIGURES.....	viii
LIST OF TABLES	ix
CHAPTER 1 Introduction	1
1.1 Background	1
1.2 Research questions and objectives	3
1.3 Research significance	6
1.4 Research methodology and process	8
1.4.1 Research methodology	8
1.4.2 Research process	10
1.5 Thesis structure.....	11
1.6 Publications related to this thesis	12
CHAPTER 2 Literature Review.....	15
2.1 Bi-level decision-making	15
2.1.1 Basic bi-level decision-making	15
2.1.2 Bi-level multi-objective decision-making	22
2.1.3 Bi-level multi-leader and/or multi-follower decision-making	23
2.2 Tri-level decision-making.....	27
2.3 Fuzzy multilevel decision-making	29
2.4 Applications of multilevel decision-making techniques	31
2.4.1 Supply chain management.....	31

2.4.2 Traffic and transportation network design.....	34
2.4.3 Energy management.....	37
2.4.4 Safety and accident management.....	39
2.5 Summary.....	41
CHAPTER 3 Large-scale Nonlinear Multilevel Decision Making.....	44
3.1 Introduction.....	44
3.2 Bi-level PSO algorithm.....	45
3.2.1 General bi-level decision problem and solution concepts.....	45
3.2.2 The bi-level PSO algorithm description.....	47
3.3 Tri-level PSO algorithm.....	53
3.3.1 General tri-level decision problem and related theoretical properties .	53
3.3.2 The tri-level PSO algorithm description.....	57
3.4 Computational study.....	61
3.4.1 Small-scale benchmark problems.....	61
3.4.2 Large-scale benchmark problems.....	69
3.4.3 Assessing the efficiency performance of the bi-level PSO algorithm..	73
3.5 Summary.....	83
CHAPTER 4 Compromise-based Fuzzy Nonlinear Bi-level Decision Making.....	85
4.1 Introduction.....	85
4.2 Preliminaries of fuzzy set theory.....	86
4.3 General fuzzy bi-level decision problem and theoretical properties.....	88
4.3.1 General fuzzy Bi-level decision problem.....	88
4.3.2 Related theoretical properties.....	90
4.4 Compromise-based PSO algorithm.....	93
4.5 Numerical examples.....	97
4.5.1 An illustrative example.....	97
4.5.2 Benchmark examples.....	101
4.6 Summary.....	102
CHAPTER 5 Tri-level Multi-follower Decision Making.....	104

5.1 Introduction	104
5.2 TLMF decision models and related theoretical properties	105
5.2.1 TLMF decision models and solution concepts	106
5.2.2 Related theoretical properties	117
5.3 TLMF <i>K</i> th-Best algorithm and a numerical example.....	124
5.3.1 TLMF <i>K</i> th-Best algorithm description	124
5.3.2 A numerical example	130
5.4 Solution evaluation.....	133
5.5 Case study.....	139
5.5.1 Case description	140
5.5.2 Model building	144
5.5.3 Numerical experiment and results analysis	146
5.5.4 Further discussions	152
5.6 Summary	154
CHAPTER 6 Application in Decentralized Vendor-managed Inventory	156
6.1 Introduction	156
6.2 Problem statement	158
6.3 Analytical model.....	162
6.4 Computational study.....	165
6.4.1 An illustrative instance	165
6.4.2 Sensitivity analysis	169
6.4.3 Assessing the efficiency performance of the TLMF <i>K</i> th-Best algorithm	176
6.5 Summary	181
CHAPTER 7 Conclusions and Further Study	183
7.1 Conclusions	183
7.2 Further study.....	186
References	188
Abbreviations	213

LIST OF FIGURES

Figure 1.1 Reasoning in the general design cycle (Vaishnavi & Kuechler Jr 2007).....	9
Figure 1.2 Thesis structure	12
Figure 3.1 The performance of the bi-level PSO algorithm following different parameter combinations	78
Figure 3.2 The average of the convergent CPU time	81
Figure 3.3 The average of the total CPU time of all iterations completed.....	82
Figure 4.1 The membership function of fuzzy number \tilde{a}	87
Figure 4.2 The convergence curves of the leader's and the follower's expected objective values	100
Figure 5.1 The organizational structure of the TLMF decision-making hierarchy...	106
Figure 5.2 Linear membership function.....	135
Figure 5.3 Hierarchical structure of the conglomerate enterprise	141
Figure 5.4 The contrastive analysis of results	152
Figure 6.1 The organizational structure of the three-echelon supply chain	159
Figure 6.2 The average of iterations and CPU time for solving the test problems ...	180
Figure 6.3 The fitted curve of CPU time following the number of buyers change...	180

LIST OF TABLES

Table 3.1 Benchmark problems and their related sources.....	62
Table 3.2 Parameters employed in the bi-level/tri-level PSO algorithms for solving problems 1-33.....	63
Table 3.3 The computational results for bi-level decision problems 1-25.....	66
Table 3.4 The computational results for tri-level decision problems 26-33.....	68
Table 3.5 The computational results for five-dimensional test problems 34(SMD1) - 45(SMD12).....	70
Table 3.6 The computational results for 10-dimensional test problems 46(SMD1) - 57(SMD12).....	71
Table 3.7 The computational results for 20-dimensional test problems 58-62.....	72
Table 3.8 Test problem dimensions.....	74
Table 3.9 The number of test problems successfully solved under each parameter combination.....	76
Table 3.10 The computational results respectively obtained by the bi-level PSO algorithm and GABB.....	79
Table 4.1 Parameters employed in the compromise-based PSO algorithm for solving problem (4.7).....	98
Table 4.2 The computational results of problem (4.7) under different compromised conditions.....	99
Table 4.3 Parameters in the PSO algorithm for solving problems in (Zhang & Lu 2005, 2007).....	101
Table 4.4 The computational results of the problem in (Zhang & Lu 2007).....	102
Table 4.5 The computational results of the problem in (Zhang & Lu 2005).....	102

Table 5.1 Notations used in the TLMF <i>K</i> th-Best algorithm.....	127
Table 5.2 Coefficients of model (5.3)	130
Table 5.3 Objective values and corresponding satisfactory degrees of decision entities in Example 5.1.....	138
Table 5.4 Notations for decision variables and parameters employed.....	143
Table 5.5 Data for the sales company	146
Table 5.6 Data for the logistics centers	146
Table 5.7 Data for the manufacturing factories.....	146
Table 5.8 The detailed computing process of the TLMF <i>K</i> th-Best algorithm	148
Table 5.9 Solutions and objective values of decision entities.....	149
Table 5.10 The satisfactory degree of decision entities towards solutions	150
Table 6.1 Notations of decision variables and parameters employed	161
Table 6.2 Data for the vendor.....	166
Table 6.3 Data for the distributors.....	166
Table 6.4 Data for the buyers	166
Table 6.5 The detailed computing process of the TLMF <i>K</i> th-Best algorithm	167
Table 6.6 Solutions and objective values of decision entities.....	168
Table 6.7 The experimental results based on the distributor's and buyer's inventory upper limits changes.....	171
Table 6.8 The experimental results based on the penalty cost changes	173
Table 6.9 The experimental results based on the distributor's transportation cost changes	174
Table 6.10 Test instances randomly generated.....	177
Table 6.11 The experimental results of the randomly generated test problems.....	178