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DEVELOPMENT OF INTEGRATED MODELS FOR DISTRIBUTION NETWORK DESIGN OF PERISHABLE PRODUCTS

ZAHRA FIROOZI

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DEVELOPMENT OF INTEGRATED MODELS FOR DISTRIBUTION NETWORK DESIGN OF PERISHABLE PRODUCTS

By

ZAHRA FIROOZI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

This thesis is dedicated to
my beloved husband for his patience, supports and encouragements;
my lovely parents for their never ending supports
and
to all those who supported me in accomplishment of this work.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF INTEGRATED MODELS FOR DISTRIBUTION NETWORK DESIGN OF PERISHABLE PRODUCTS

By

ZAHRA FIROOZI

January 2015

Chairman: Professor Datin Dr Napsiah Ismail, PhD.

Faculty : Engineering

Over the last few years, inventory-location network design models due to the incorporation of two main decisions in network design, meaning inventory control and facility location, has attracted great attention from both industries and researchers. Existing inventory-location models are mainly applicable for non-perishable inventories. However, since, perishable inventory comprise a large proportion of the inventory distributed through the distribution networks, and due to the important role of the network design on the final cost and quality of the products, development of inventory-location models suitable for perishable inventory is of great importance. Therefore, the objective of this research is development of integrated inventory-location models for distribution network design of fixed- and random-lifetime perishable products, that has been achieved through the following four phases.

The first phase is to select the best structure for the distribution network between a centralized and decentralized configuration. Previous research works that admire a centralized structure consisting of suppliers, distribution centers and retailers, considered for simplicity that the products dispatched from the supplier are maintained at the distribution centers locations before being demanded by the customer. It is equivalent to this assumption that if a customer places an order to a retailer, and the retailer is out-of-stock the customer waits for the products to be available. However, in practice it is not true and a fraction of customers encountering stock-out switches to other markets. To this end, the first part of this study formulates the centralized and decentralized structures when inventory can be stored at both retailers' and DCs' location. Sensitivity analysis is conducted to determine the value of centralization. Results indicate that the value of centralization is

dependent on the parameters of the problem, and that for the parameters of the problem considered in this research, a centralized structure has been more efficient. So, for the rest of this research a centralized structure is considered for the distribution network.

The second phase of this research is to determine the best optimization approach to formulate the problem between an integrated and a decoupled method. Hence, the inventory-location model is formulated for fixed-lifetime perishable product once by an integrated model and another time by a decoupled model. A memetic algorithm (MA) is developed to solve the integrated model, and the Lingo software is applied to solve the decoupled model. Results show that up to 5.7% cost reduction is achieved by applying the integrated model. The developed MA is compared with a GA from literature. Result indicates that in terms of solution quality, MA is up to 22.13% superior to GA, but up to 4.17 times slower than that. Therefore, the third phase of this research develops a much efficient solution method based on Lagrangian relaxation to solve the integrated inventory-location model for fixed-lifetime perishable products. Results show that the Lagrangian relaxation algorithm is in average 255 times faster than GA, and in terms of solution quality is up to 22.13% better than GA. The developed model, other than facility location and inventory control decision for a distribution network, provides the managers the opportunity to select among higher-inventory-cost options that lead to longer-lifetime for products and less costly options that result in having products with shorter lifetimes.

Finally, the last phase of this study develops an integrated inventory-location model for the network design of random-lifetime perishable products. The model defines the randomness of product lifetimes by discrete scenarios, and therefore, provides solutions that perform well under all defined scenarios. A Lagrangian relaxation-based heuristic algorithm is developed to solve the model. The algorithm produces solutions that are within 0.027% of optimality gap.

Abstrak of tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN MODEL BERSEPADU UNTUK REKA BENTUK RANGKAIAN BARANGAN MUDAH ROSAK

Oleh

ZAHRA FIROOZI

Januari 2015

Pengerusi: Profesor Datin Dr. Napsiah Ismail, PhD.

Fakulti : Kejuruteraan

Sejak beberapa tahun kebelakangan in, model-model rangkaian sumber bekalan berpaksikan tempat dan kawalan telah menarik perhatian pihak industri dan penyelidik. Model-model yang berdasarkan tempat tertumpunya sumber bekalan hanya relevan untuk bahan-bahan yang tidak mudah lapuk atau rosak. Pembangunan model sumber bekalan masa kini menjadi lebih penting memandangkan bekalan bahan yang mudah rosak menjadi sebahagian besar daripada rangkaian pengedaran dan kepentingan rangkaian reka bentuk terhadap kos dan kualiti sesuatu produk. Justeru itu, fokus penyelidikan ini adalah pembangunan model rangkaian pengagihan lokasi inventori bersepadu untuk barang mudah rosak dan tidak mudah rosak, Objektif penyelidikan ini dicapai melalui empat fasa berikut.

Fasa pertama ialah untuk memilih struktur terbaik untuk rangkaian pengagihan antara satu konfigurasi terpusat dan terpancar. Kerja-kerja penyelidikan dahulu yang mengikuti satu struktur terpusat mengandungi pembekal, pusat pengedaran dan peruncit, dianggap untuk kesederhanaan yang produk menghantar dari pembekal dikekalkan pada lokasi pusat pengedaran sebelum didesak oleh pelanggan. Bersamaan andaian ini bahawa jika seorang pelanggan meletakkan satu perintah kepada seorang peruncit, dan peruncit kehabisan barangan maka pelanggan akan menunggu bagi produk itu mesti diadakan. Bagaimanapun, pada praktiknya ia tak benar dan satu bahagian daripada pelanggan mendapat saham keluar pertukaran kepada lain-lain pasaran. Bagi akhir ini, bahagian pertama kajian ini merumuskan dan menilai struktur terpancar dan terpusat apabila inventori boleh disimpan di kedua-dua peruncit dan DCs' lokasi. Keputusan menunjukkan bahawa nilai pemusatan bergantung di parameter bermasalah. Lantarannya, tiada penghakiman boleh dibuat tentang yang mana struktur menguntungkan untuk satu rangkaian melainkan, selepas membuat satu perbandingan antara dua struktur. Keputusan

menunjukkan bahawa output bagi rangkaian berpusat bergantung kepada masalah parameter dan rangkaian berpusat terbukti lebih efisyen. Oleh yang demikian, rangkaian berpusat akan menjadi topik utama dalam rangkaian pengedaran.

Fasa kedua penyelidikan ini bermatlamat untuk menentukan kaedah optimisi yang terbaik bagi memformulasi masalah di antara model rangkaian bersepadu dan nyahganding. Maka, satu rangkaian bersepadu dan model nyahganding dibangunkan untuk reka bentuk rangkaian barangan mudah rosak hayat ditetapkan, di mana, model bersepadu mengoptimumkan keputusan rekabentuk rangkaian serentak dan, kaedah nyahganding mengoptimumkan keputusan akibatnya. Algoritma memetic dibangunkan untuk menyelesaikan model bersepadu dan perisian Lingo digunakan ke atas menyelesaikan nyahganding model. Analisis kepekaan dijalankan untuk menilai nilai integrasi. Keputusan menunjukkan bahawa sehingga 5.7% pengurangan kos dicapai dengan menggunakan model bersepadu. Yang dibanginkan iaitu MA akan dibandingkan dengan GA dari kesusasteraan. Keputusan menunjukkan itu dalam soal kualiti penyelesaian, MA adalah sehingga 22.13% hebat kepada GA, tetapi sehingga 4.17 kali lebih perlahan daripada itu. Lantarannya, fasa ketiga penyelidikan ini membangunkan satu banyak kaedah penyelesaian cekap berdasarkan Lagrangian rehat menyelesaikan model rekabentuk rangkaian bersepadu untuk produk musnah dibangunkan dalam fasa 2. Keputusan menunjukkan bahawa algoritma rehat Lagrangian berada dalam sederhana 255 kali lebih pantas daripada GA, dan dalam soal kualiti penyelesaian adalah sehingga 22.13% lebih baik daripada GA. Model yang telah dihasilkan membantu pengurus memilih sumber bekalan berkos tinggi dan membantu produk untuk tahan lebih lama ataupun pilihan yang lebih mahal tetapi menyebabkan produk mempunyai jangka hayat yang pendek.

Selain daripada produk-produk hayat ditetapkan terdapat satu lagi pelbagai jenis barangan mudah rosak dikenali sebagai barang-barang hayat rawak yang merosot secara rawak. Tidak mempedulikan kerawakan hayat boleh menyebabkan kos tinggi kepada sistem agihan. Lantarannya, di peringkat akhir kajian ini, satu model bersepadu dibangunkan untuk reka bentuk rangkaian barangan mudah rosak hayat rawak menerusi senario secara data dan seterusnya membuktikan bahawa model tersebut boleh diaplikasi dalam apa jua jenis senario. Satu Lagrangian algoritma heuristik berasaskan kelonggaran dibangunkan untuk menyelesaikan model. Algoritma menghasilkan penyelesaian dengan sehingga 0.027% keoptimuman jurang.

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I certify that a Thesis Examination Committee has met on 23 January 2015 to conduct the final examination of Zahra Firoozi on her thesis entitled "Development of Integrated models for distribution network design of perishable products" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Zulkiflle Leman, PhD
Associate Professor
Faculty of Engineering
University Putra Malaysia
(Chairman)

Shamsuddin Sulaiman, PhD
Professor
Faculty of Engineering
University Putra Malaysia
(Internal Examiner)

Norzima Zulkifli, PhD
Associate Professor
Faculty of Engineering
University Putra Malaysia
(Internal Examiner)

Türkay Dereli, PhD
Professor
Faculty of Engineering
Gaziantep University
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:12 March 2015

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Napsiah Ismail, PhD
Professor
Faculty of Engineering
University Putra Malaysia
(Chairman)

Mohd Khairol Anuar Mohd Ariffin, PhD
Associate Professor
Faculty of Engineering
University Putra Malaysia
(Member)

Tang Sai Hong, PhD
Associate Professor
Faculty of Engineering
University Putra Malaysia
(Member)

Azizollah Memariani, PhD
Professor
Faculty of Mathematics and Computer Science
Tehran University of Economic Sciences
(Member)

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Committee:

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Member of
Supervisory
Committee:

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Name of
Member of
Supervisory
Committee:

TABLE OF CONTENTS

		Page
ABSTRACT		i
ABSTRAK		III
ACKNOWLEDGEMENTS		V
APPROVAL		VI
DECLARATION		VIII
LIST OF TABLES		XIII
LIST OF FIGURES		XV
LIST OF ABBREVIATIONS		XX
CHAPTER		
1	**INTRODUCTION**	1
	1.1 Background	1
	1.2 Problem statement	2
	1.3 Objectives	3
	1.4 Contributions of the study	4
	1.5 Scope of the study	4
	1.6 Outline of thesis	5
2	**LITERATURE REVIEW**	6
	2.1 Introduction	6
	2.2 Facility location in supply chain management	6
	2.3 Facility location models	7
	2.3.1 Single-layer and multi-layer models	8
	2.3.2 Single-product and multi-product models	8
	2.3.3 Static and dynamic models	9
	2.3.4 Deterministic and stochastic models	9
	2.3.5 Single-sourcing and multi-sourcing	9
	2.4 Inventory control problems	9
	2.4.1 Economic order quantity model	10
	2.4.2 Continuous (Q, r) model	11
	2.4.3 Multi-echelon inventory control	12
	2.4.4 Inventory centralization	12
	2.5 Integrated distribution network design models	13
	2.5.1 Capacitated location model with risk pooling	13
	2.5.2 Inventory-location models	15
	2.6 Network structuring	23
	2.7 Solution methods	25
	2.7.1 Exact methods	25
	2.7.2 Heuristic methods	27
	2.7.3 Hybrid algorithms	27
	2.7.4 Memetic algorithm	27
	2.8 Overall shortcoming of existing models	32
	2.9 Summary	33
3	**SCHEME OF RESEARCH**	34

3.1 Introduction 34
3.2 Scheme of applied research methodology 34
3.2.1 Phase 1 36
3.2.2 Phase 2 38
3.2.3 Phase 3 38
3.2.4 Phase 4 40

4 **CENTRALIZATION AND DECENTRALIZATION OF DISTRIBUTION NETWORKS** 42
4.1 Introduction 42
4.2 Methodology 43
4.2.1 Centralized system 43
4.2.2 Decentralized system 50
4.2.3 Solution method 52
4.3 Results and discussion 58
4.3.1 Model validation 58
4.3.2 Value of centralization 65
4.3.3 Algorithm performance 71
4.4 Summary 76

5 **INTEGRATION OF DISTRIBUTION NETWORK DESIGN DECISIONS AND INVENTORY CONTROL DECISIONS OF FIXED-LIFE TIME PRODUCTS** 78
5.1 Introduction 78
5.2 Methodology 78
5.2.1 Problem definition and modeling 78
5.2.2 Solution methods 83
5.3 Results and discussion 87
5.3.1 Algorithm evaluation 87
5.3.2 Model validation 91
5.3.3 Value of integration 93
5.4 Summary 95

6 **DISTRIBUTION NETWORK DESIGN FOR FIXED-LIFETIME PRODUCTS** 97
6.1 Introduction 97
6.2 Methodology 97
6.2.1 Problem definition 97
6.2.2 Solution method 99
6.3 Results and discussion 105
6.3.1 Model validation 106
6.3.2 Algorithm evaluation 110
6.3.3 Application of the model 114
6.4 Summary 115

7 **DISTRIBUTION NETWORK DESIGN FOR RANDOM-**

LIFETIME PRODUCTS 116
7.1 Introduction 116
7.2 Methodology 116
7.2.1 Problem definition and modeling 116
7.2.2 Model assumptions 117
7.2.3 Solution method 121
7.3 Results and discussion 124
7.3.1 Algorithm evaluation 126
7.3.2 Model validation 127
7.3.3 Case study 129
7.4 Summary 134

8 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORKS 136
8.1 Introduction 136
8.2 Summary of the research 136
8.3 Recommendation for future work 137

REFERENCES 139
APPENDICES 152
BIODATA OF STUDENT 156
LIST OF PUBLICATIONS 157

LIST OF TABLES

Table	Page
4-1 Inventory and ordering cost parameters	59
4-2 Parameters of the Lagrangian relaxation heuristic algorithm	59
4-3 Performance of the algorithm used to solve the centralized model	72
4-4 Parameters of Lagrangian relaxation used to solve the centralized model	74
4-5 Parameters of the GA by Diabat et al. (2009)	74
4-6 Comparison of the results obtained by the Lagrangian relaxation algorithm used to solve the centralized model and GA for 15-node data set	75
4-7 Comparison of the results obtained by Lagrangian relaxation algorithm used to solve the centralized model and GA for 49-node data set	76
5-1 Parameters of the developed MA used to solve the integrated model	88
5-2 Parameters of the GA developed by Diabat et al. (2009)	88
5-3 Comparison of MA and GA for 49-node dataset with β=0.0004 and θ=0.01	90
5-4 Comparison of the MA and GA for 49-node dataset with β=0.00001 and θ=0.001	91
5-5 Comparison of MA and Lingo	92
5-6 Average value of integration versus changes in lifetime and fixed ordering cost	95
6-1 Parameter of the Lagrangian relaxation algorithm used to solve the integrated model for fixed-lifetime products	106
6-2 Performance of the Lagrangian relaxation algorithm used to solve the integrated model for fixed-lifetime products	111
6-3 Parameters of the GA developed by Diabat et al. (2009)	111
6-4 Comparison of Lagrangian relaxation and GA for 49-node data set with β=0.0004 and θ=0.01	113
6-5 Comparison of the Lagrangian relaxation and GA for 49-node data set with β=0.00001 and θ=0.001	114
6-6 Lifetime and inventory holding cost of blood platelet driven from (Haijema et al., 2007)	115
6-7 Total cost of the available alternatives	115
7-1 Parameters of the three-scenario problem	125
7-2 Parameters of the five-scenario problem	125

7-3 Parameters of the seven-scenario problem 125
7-4 Parameter of Lagrangian relaxation algorithm used to solve the integrated network design model for random-lifetime products 125
7-5 Performance of the Lagrangian relation algorithm used to solve the integrated network design model for random-lifetime products 126
7-6 Average gap and CPU time of the algorithm used to solve the integrated network design model for random-lifetime products 127
7-7 Comparison of LR and Lingo 127
7-8 Comparison of deterministic and stochastic solutions 128
7-9 Demand parameters (Ton) 130
7-10 Distance between retailers (Kilometers) 131
7-11 Distance between supplier and retailers (Kilometers) 131
7-12 lead-times (day) 132
7-13 Possible unpleasant scenarios that affects the products 132

LIST OF FIGURES

Figure **Page**

2-1 Total cost curve in EOQ model (Stevenson, 2008) 11
2-2 Inventory level versus time in (Q, r) model (Stevenson, 2008) 11
2-3 Genetic algorithm steps 29
2-4 Single-point crossover 30
2-5 Multiple-point mutation 31
3-1 Scheme of applied research methodology in this study 35
3-2 Flow of research for phase 1 (Chapter 4) 37
3-3 Flow of research for phase 2 and 3 39
3-4 Flow of research for phase 4 (Chapter 7) 41
4-1 Profile of inventory versus time for situation 1 46
4-2 Profile of inventory versus time for situation 2 47
4-3 Profile of inventory versus time for situation 3 48
-4 Total inventory and ordering cost versus k (h=5, H=1, A=10, a=1, n=5) 49
4-5 Total inventory and ordering cost versus k (h=1, H=5, A=1, a=10, n=5) 49
4-6 Pseudo code for the lower bound calculation of the algorithm used to solve the centralized model 55
4-7 Pseudo code for the upper bound calculation of the algorithm used to solve the centralized model 57
4-8 Sensitivity of the objective functions vs. inventory holding cost of DCs (case 1) 60
4-9 Sensitivity of the objective functions vs. ordering cost of DCs (case 1) 60
4-10 Sensitivity of the objective functions vs. variances of demands (case 1) 60
4-11 Sensitivity of the objective functions vs. transportation cost (case 1) 60
4-12 Sensitivity of the objective functions vs. inventory holding cost of DCs (case 2) 60
4-13 Sensitivity of the objective functions vs. ordering cost of DCs (case 2) 60
4-14 Sensitivity of the objective functions vs. variances of demands (case 2) 60
4-15 Sensitivity of the objective functions vs. transportation cost (case 2) 60

4-16 Sensitivity of the objective functions vs. inventory holding cost of DCs (case 3) 61
4-17 Sensitivity of the objective functions vs. ordering cost of DCs (case 3) 61
4-18 Sensitivity of the objective functions vs. variances of demands (case 3) 61
4-19 Sensitivity of the objective functions vs. transportation cost (case 3) 61
4-20 Sensitivity of the objective functions vs. inventory holding cost of DCs (case 4) 61
4-21 Sensitivity of the objective functions vs. ordering cost of DCs (case 4) 61
4-22 Sensitivity of the objective functions vs. variances of demands (case 4) 61
4-23 Sensitivity of the objective functions vs. transportation cost (case 4) 61
4-24 Sensitivity of the objective functions vs. inventory holding cost of DCs (case 5) 62
4-25 Sensitivity of the objective functions vs. ordering cost of DCs (case 5) 62
4-26 Sensitivity of the objective functions vs. variances of demands (case 5) 62
4-27 Sensitivity of the objective functions vs. transportation cost (case 5) 62
4-28 Sensitivity of the objective functions vs. inventory holding cost of DCs (case 6) 62
4-29 Sensitivity of the objective functions vs. ordering cost of DCs (case 6) 62
4-30 Sensitivity of the objective functions vs. variances of demands (case 6) 62
4-31 Sensitivity of the objective functions vs. transportation cost (case 6) 62
4-32 Sensitivity of the objective functions vs. inventory holding cost of DCs (case 7) 63
4-33 Sensitivity of the objective functions vs. ordering cost of DCs (case 7) 63
4-34 Sensitivity of the objective functions vs. variances of demands (case 7) 63
4-35 Sensitivity of the objective functions vs. transportation cost (case 7) 63
4-36 Sensitivity of the objective functions vs. inventory holding cost of DCs (case 8) 63
4-37 Sensitivity of the objective functions vs. ordering cost of DCs (case 8) 63
4-38 Sensitivity of the objective functions vs. variances of demands (case 8) 63
4-39 Sensitivity of the objective functions vs. transportation cost (case 8) 63
4-40 Sensitivity of the objective functions vs. inventory holding cost of DCs (case 9) 64
4-41 Sensitivity of the objective functions vs. ordering cost of DCs (case 9) 64

4-42 Sensitivity of the objective functions vs. variances of demands (case 9) 64
4-43 Sensitivity of the objective functions vs. transportation cost (case 9) 64
4-44 Sensitivity of VOC vs. inventory holding cost of DCs (case 1) 66
4-45 Sensitivity of VOC vs. ordering cost of DCs (case 1) 66
4-46 Sensitivity of VOC vs. variances of demands (case 1) 66
4-47 Sensitivity of VOC vs. transportation cost (case 1) 66
4-48 Sensitivity of VOC vs. inventory holding cost of DCs (case 2) 66
4-49 Sensitivity of VOC vs. ordering cost of DCs (case 2) 66
4-50 Sensitivity of VOC vs. variances of demands (case 2) 66
4-51 Sensitivity of VOC vs. transportation cost (case 2) 66
4-52 Sensitivity of VOC vs. inventory holding cost of DCs (case 3) 67
4-53 Sensitivity of VOC vs. ordering cost of DCs (case 3) 67
4-54 Sensitivity of VOC vs. variances of demands (case 3) 67
4-55 Sensitivity of VOC vs. transportation cost (case 3) 67
4-56 Sensitivity of VOC vs. inventory holding cost of DCs (case 4) 67
4-57 Sensitivity of VOC vs. ordering cost of DCs (case 4) 67
4-58 Sensitivity of VOC vs. variances of demands (case 4) 67
4-59 Sensitivity of VOC vs. transportation cost (case 4) 67
4-60 Sensitivity of VOC vs. inventory holding cost of DCs (case 5) 68
4-61 Sensitivity of VOC vs. ordering cost of DCs (case 5) 68
4-62 Sensitivity of VOC vs. variances of demands (case 5) 68
4-63 Sensitivity of VOC vs. transportation cost (case 5) 68
4-64 Sensitivity of VOC vs. inventory holding cost of DCs (case 6) 68
4-65 Sensitivity of VOC vs. ordering cost of DCs (case 6) 68
4-66 Sensitivity of VOC vs. variances of demands (case 6) 68
4-67 Sensitivity of VOC vs. transportation cost (case 6) 68
4-68 Sensitivity of VOC vs. inventory holding cost of DCs (case 7) 69
4-69 Sensitivity of VOC vs. ordering cost of DCs (case 7) 69
4-70 Sensitivity of VOC vs. variances of demands (case 7) 69
4-71 Sensitivity of VOC vs. transportation cost (case 7) 69
4-72 Sensitivity of VOC vs. inventory holding cost of DCs (case 8) 69
4-73 Sensitivity of VOC vs. ordering cost of DCs (case 8) 69
4-74 Sensitivity of VOC vs. variances of demands (case 8) 69

4-75 Sensitivity of VOC vs. transportation cost (case 8) 69
4-76 Sensitivity of VOC vs. inventory holding cost of DCs (case 9) 70
4-77 Sensitivity of VOC vs. ordering cost of DCs (case 9) 70
4-78 Sensitivity of VOC vs. variances of demands (case 9) 70
4-79 Sensitivity of VOC vs. transportation cost (case 9) 70
5-1 Inventory cycle and lifetime 80
5-2 Profile of inventory versus time 81
5-3 Chromosome representation 84
5-4 Procedure of developed MA algorithm 87
5-5 Average value of integration versus changes in lifetime and holding inventory cost 94
5-6 Average value of integration versus changes in lifetime and fixed ordering cost 94
5-7 Average value of integration versus changes in lifetime and variance of demand 95
6-1 Pseudo code for the lower bound calculation of the algorithm used to solve the integrated model for fixed-lifetime products 102
6-2 Pseudo code for the upper bound calculation of the algorithm used to solve the integrated model for fixed-lifetime products 104
6-3 Pseudo code of the Lagrangian relaxation-based heuristic used to solve the integrated model for fixed-lifetime products 105
6-4 Sensitivity of the objective function to changes in the lifetime for 49 node data set 107
6-5 Sensitivity of the objective function to changes in the lifetime for 15-node data set 107
6-6 Sensitivity of the objective function to changes in the inventory cost for 15-node date set 108
6-7 Sensitivity of the objective function to changes in the inventory cost for 49-node date set 108
6-8 Sensitivity of the objective function to changes in the variances of demands for 15-node data set 109
6-9 Sensitivity of the objective function to changes in the variances of demands for 49-node data set 109

6-10 Sensitivity of the objective function to changes in the fixed installation cost for 15-node data sets 110
6-11 Sensitivity of the objective function to changes in the fixed installation cost for 49-node data sets 110
7-1 the optimal distribution network for the pistachio processing company 134

LIST OF ABBREVIATIONS

CFLP	Capacitated Facility Location Problem
CLMRP	Capacitated Location Model with Risk Pooling
CPU	Central Processing Unit
DC	Distribution Center
DND	Distribution Network Design
EOQ	Economic Order Quantity
GA	Genetic Algorithm
GH	Greedy Heuristic
GWA	Generalized Weiszfeld Algorithm
LMRP	Location Model with Risk Pooling
MA	Memetic Algorithm
MINLP	Mixed Integer Non-Linear Programming
MISL	Multi-echelon Inventory Single-echelon Location
NP-Hard	Non-Polynomial Hard
ROP	Re-Order Point
SA	Simulated Annealing
SIML	Single-echelon Inventory Multi-echelon Location
SISL	Single-echelon Inventory Single-echelon Location
SLMRP	Stochastic Location Model with Risk Pooling
s.t.	Subject To
UFLP	Un-capacitated Facility Location Problem
VOC	Value Of Centralization

CHAPTER 1

INTRODUCTION

1.1 Background

Distribution network design (DND) is one of the most significant and challenging decision problems in logistics and supply chain management (Altiparmak et al., 2006; Faccio et al., 2011). In today's competitive environment, pressure of growing costs, sources of uncertainty, and introduction of short life-cycle products have caused this area of research to gain much attention among both researchers and industries.

In a distribution network, items are produced at the manufacturers and shipped to the warehouses and then to the retailers to finally meet the customers' demand. Distribution network design is a complex process since decisions to be made for designing a distribution network are highly interrelated (Ozsen et al., 2008). For instance, any changes in the network configuration, i.e. the number and location of facilities, influence the transportation and replenishment cost and the optimal inventory policy. Owing to these interrelationships, a huge amount of potential cost saving would be lost if relevant decisions are not optimized simultaneously (Miranda and Garrido, 2008).

Moreover, the components of cost associated with network design decisions are estimated to contribute about 10% to 20% of the sale (Punakivi and Hinkka, 2006). This fact implies that an efficient design of a distribution network can considerably affect the cost and quality of the final products (Dabbene et al., 2008).

In the real world, an extensive proportion of the products distribute worldwide are perishable (Minner and Transchel, 2010; Jia and Hu, 2011). For instance, 50% of sales in the U.S. grocery industry are due to perishable products (Ferguson and Ketzenberg, 2006), and in the area of blood management, more than 92 million units of blood, which are perishable, are collected globally every year, according to the World Health Organization (WHO) (2011). Medicines, pharmaceutical products, and many industrial products are other varieties of perishable goods.

Furthermore, a large number of distribution networks in the world are dealing with distribution and storage of these perishable products (Hsu et al., 2007; Broekmeulen and van Donselaar, 2009). Therefore, designing integrated distribution network for perishable products is of a great magnitude. However, only recently, researchers have focused on developing integrated DND models for perishable products that optimize the distribution network decisions simultaneously.

This research focuses on development of models and solution methods for distribution network design of perishable products. Hereafter in this text, the words structure and system and the words warehouse and distribution center are interchangeably used.

1.2 Problem statement

Inventory-location models are important variety of network design models made by incorporation of facility location and inventory control decisions. The main problem with existing inventory-location models is an assumption that considers products can be stored indefinitely in the distribution network. This assumption is not in favor of perishable inventories that have limited lifetimes. Moreover, since, perishable inventories comprise a large proportion of the inventory distributed through the distribution networks (Jia and Hu, 2011), and due to the important role of the network design on the cost and quality of the products, development of inventory-location models suitable for perishable inventory is of significant importance.

In order to develop successful and efficient inventory-location network design models, two imperative issues need to be considered as follows (Baghalian et al., 2013):

(1). **Determining the optimal network structure**: Network structuring involves centralization or decentralization of a distribution network; that is, to determine whether the combination of facilities should be of a centralized or a decentralized system (Min and Zhou, 2002). In a distribution network consisting of a supplier and N retailers, centralization can be applied by aggregating demands of retailers into several distribution centers (DCs) that operate as intermediate facilities. The DCs, then, order products from the supplier and keep the inventory of products to satisfy the demands of retailers. On the opposite side of centralization, stands the so-called decentralized system in which each retailer directly orders to the supplier and keeps its own inventory. The advantages (Berman et al., 2011; Gerchak and He, 2003; Benjaafar et al., 2005) and disadvantages (Gerchak and He, 2003; Pedersen et al., 2012) of centralization have been discussed in previous researches. However, traditionally it was considered that, in a centralized system no inventory is stored in the retailers' location. In other words, it is assumed that if a retailer is out-of-stock, the customer wait for the goods to be available. However, in practice it is not always true, and a fraction of customers switch to other markets if they face stock out (Bijvank and Vis, 2011). So, in order to have a precise comparison between a centralized and a decentralized system, to determine the best structure for the distribution network, the inventory and ordering costs at retailers, as well as those at the DCs need to be taken into account.

(2). **Simultaneously integration of related decisions**: The decisions to be made for designing a distribution network are highly interrelated (Ozsen et al., 2008), and due to this interrelationship, it is expected that a huge amount of potential cost saving would be lost if relevant decisions are not optimized simultaneously (Miranda and Garrido, 2008). In spite of that, traditional inventory-location network design models suffer from simultaneous integration of the perishable inventory control and other network design decisions. So studies need to be conducted to obtain the potential benefits that could be achieved by incorporation of perishable inventory control decisions into facility location models by an integrated approach rather than a decoupled approach.

In addition, perishable products are categorized on the basis of their lifetimes into two groups of fixed-lifetime and variable-lifetime items (Kouki et al., 2013a). Fixed-lifetime items have a predetermined expiry date such as many processed foods. However, random lifetime items have no determined expiry date such as fresh foods, fruits and vegetables. Therefore, models need to be developed for distribution network design of perishable products for both fixed-lifetime and variable-lifetime items.

Most of the existing works on perishable inventory that studied random-lifetime items considered that lifetime follow a known distribution function. Though, many actual worlds' conditions such as unusual changes in climate or failure of transportation and storage facilities which are of a low possibility of happening, but, have significant impacts on product lifetimes are difficult to be described by known probability distribution functions. Moreover, an unsuitable distribution function may lead to drastically unsatisfactory results (Gürler and Özkaya, 2008). Therefore, the developed models for variable-lifetime products must perform well under any possible lifetime behavior of the products. Such a goal can be achieved by defining uncertainty of life-time using discrete scenarios.

1.3 Objectives

The main objectives of this study are listed in the following.

(1). To develop an inventory-location network design model for selecting the best structure for the distribution network between a centralized and a decentralized structure.

(2). To develop and solve an integrated inventory-location model for distribution network design of fixed-lifetime perishable products.

(3). To develop and solve an integrated inventory-location model for distribution network design of random-lifetime perishable products.

1.4 Contributions of the study

The most important contribution of this study is development of inventory-location models and solution methods for fixed- and random-lifetime perishable products which have the following features.

(1). The models develop a trade-off between selecting higher-inventory-cost options that lead to longer lifetime for products and less-costly options that result in shorter lifetime for products.

(2). The model developed for random-lifetime perishable products defines the randomness of product lifetimes by worst-case scenarios, and provides solutions that perform well under all defined scenarios.

1.5 Scope of the study

Distribution network design models are broadly classified into four groups of (1) inventory-location models, (2) inventory-routing models, (3) location-routing models, and (4) inventory-location-routing models. The scope of this thesis covers the first category.

In addition, there are three planning levels in supply chain management known as strategic or long-term, tactical or mid-term, and operational or short-term level. Strategic level is related to decisions regarding the number and location of facilities and structure of the supply chain network. Tactical planning level affects the quantity and frequency of orders. Finally, the operational planning level includes scheduling, assignment of loads to customers' orders and routing of vehicles. The last level of planning needs detail information such as the number of personnel, number of working days, exact order quantity of each customer and so on. The developed models of this study integrate the strategic and tactical decision levels, and so these models are not applicable for short-term planning decisions.

The developed models of this study are formulated for a single product. Although, it does not necessarily imply that the models can only be used for a distribution network with one type of product. Rather, it means that all kinds of products should have the same cost parameters. Such an assumption is also a common case in reality, since, frequently happens that a distribution network is dealing with multiple products but regardless of the variety of products, they all are treated in the same manner from the cost point of view. For instance, the inventory holding cost is usually computed base of the amount of products and the period of time they are being stored in the warehouse and it usually does not vary depending on the types of the product that are stored.

1.6 Outline of thesis

The remainder of this thesis consists of seven chapters, which are organized as follows: Chapter 2 provides background materials for the work done in this research. Moreover, the relevant researches to the subject of this study are reviewed, and some main drawbacks of the existing literature and the contributions of this study to cover them are outlined. Chapter 3 is dedicated to displaying the overall flow of this research, and enumerating the models and solution techniques that are developed and applied in this study. Chapter 4 to 7 are related to the objectives of this study where, Chapters 4 is related to objective 1, Chapter 5 and 6 are related to objective 2, and chapter 7 is related to the last objectives. Each one of these chapters has its own methodology, result and conclusion. Finally, Chapter 8 provides a summary of this research and gives recommendation for future researches.

REFERENCES

Aghezzaf, E. (2005). "Capacity planning and warehouse location in supply chains with uncertain demands". Journal of the Operational Research Society, 56(4) PP: 453-462.

Ağrali, S., Geunes, J. and Taşkin, Z. C. (2012). "A facility location model with safety stock costs: Analysis of the cost of single-sourcing requirements". Journal of Global Optimization, 54(3) PP: 551-581.

Ahmadi-Javid, A. and Seddighi, A. H. (2012). "A location-routing-inventory model for designing multisource distribution networks". Engineering Optimization, 44(6) PP: 637-656.

Ahmadi Javid, A. and Azad, N. (2010). "Incorporating location, routing and inventory decisions in supply chain network design". Transportation Research Part E: Logistics and Transportation Review, 46(5) PP: 582-597.

Ahumada, O., Rene Villalobos, J. and Nicholas Mason, A. (2012). "Tactical planning of the production and distribution of fresh agricultural products under uncertainty". Agricultural Systems, 112(1) PP: 17-26.

Altiparmak, F., Gen, M., Lin, L. and Paksoy, T. (2006). "A genetic algorithm approach for multi-objective optimization of supply chain networks". Computers & Industrial Engineering, 51(1) PP: 196-215.

Ambrosino, D. and Grazia Scutellà, M. (2005). "Distribution network design: New problems and related models". European Journal of Operational Research, 165(3) PP: 610-624.

Amorim, P., Meyr, H., Almeder, C. and Almada-Lobo, B. (2013). "Managing perishability in production-distribution planning: a discussion and review". Flexible Services and Manufacturing Journal, 25(3) PP: 389-413.

Antunes, A. and Peeters, D. (2001). "On solving complex multi-period location models using simulated annealing". European Journal of Operational Research, 130(1) PP: 190-201.

Anupindi, R. and Bassok, Y. (1999). "Centralization of stocks: Retailers vs. manufacturer". Management Science, 45(2) PP: 178-191.

Askin, R. G., Baffo, I. and Xia, M. (2014). "Multi-commodity warehouse location and distribution planning with inventory consideration". International Journal of Production Research, 52(7) PP: 1897-1910.

Atamtürk, A., Berenguer, G. and Shen, Z. J. M. (2012). "A conic integer programming approach to stochastic joint location-inventory problems". Operations Research, 60(2) PP: 366-381.

Baghalian, A., Rezapour, S. and Farahani, R. Z. (2013). "Robust supply chain network design with service level against disruptions and demand uncertainties: A real-life case". European Journal of Operational Research, 227(1) PP: 199-215.

Barnhart, C., Johnson, E. L., Nemhauser, G. L., Savelsbergh, M. W. P. and Vance, P. H. (1998). "Branch-and-price: Column generation for solving huge integer programs". Operations Research, 46(3) PP: 316-329.

Benjaafar, S., Cooper, W. L. and Kim, J. S. (2005). "On the benefits of pooling in production-inventory systems". Management Science, 51(4) PP: 548-565.

Berman, O., Krass, D. and Mahdi Tajbakhsh, M. (2011). "On the benefits of risk pooling in inventory management". Production and Operations Management, 20(1) PP: 57-71.

Berman, O., Krass, D. and Tajbakhsh, M. M. (2012). "A coordinated location-inventory model". European Journal of Operational Research, 217(3) PP: 500-508.

Bijvank, M. and Vis, I. F. A. (2011). "Lost-sales inventory theory: A review". European Journal of Operational Research, 215(1) PP: 1-13.

Brahimi, N. and Khan, S. A. (2014). "Warehouse location with production, inventory, and distribution decisions: A case study in the lube oil industry". 4OR, 12(2) PP: 175-197.

Broekmeulen, R. a. C. M. and Van Donselaar, K. H. (2009). "A heuristic to manage perishable inventory with batch ordering, positive lead-times, and time-varying demand". Computers & Operations Research, 36(11) PP: 3013-3018.

Buschkühl, L., Sahling, F., Helber, S. and Tempelmeier, H. (2010). "Dynamic capacitated lot-sizing problems: A classification and review of solution approaches". OR Spectrum, 32(2) PP: 231-261.

Cabrera, G., Miranda, P. A., Cabrera, E., Soto, R., Crawford, B., Rubio, J. M. and Paredes, F. (2013). "Solving a novel inventory location model with stochastic constraints and (R,s,S) inventory control policy". Mathematical Problems in Engineering, 2013(2013) PP: 1-12.

Cai, X. and Du, D. L. (2009). "On the effects of risk pooling in supply chain management: Review and extensions". Acta Mathematicae Applicatae Sinica, 25(4) PP: 709-722.

Chang, P.-L. and Lin, C.-T. (1991). "On the effect of centralization on expected costs in a multi-location newsboy problem". Journal of the Operational Research Society, 42(11) PP: 1025-1030.

Chen, M.-S. and Lin, C.-T. (1989). "Effects of Centralization on Expected Costs in a Multi-Location Newsboy Problem". The Journal of the Operational Research Society, 40(6) PP: 597-602.

Chen, M.-S. and Lin, C.-T. (1990). "Example of disbenefits of centralized stocking". Journal of the Operational Research Society, 41(3) PP: 259-262.

Chuang, C.-L. and Lin, R.-H. (2007). "A maximum expected covering model for an ambulance location problem". Journal of the Chinese Institute of Industrial Engineers, 24(6) PP: 468-474.

Coelho, L. C. and Laporte, G. (2014). "Optimal joint replenishment, delivery and inventory management policies for perishable products". Computers & Operations Research, 47(1) PP: 42-52.

Dabbene, F., Gay, P. and Sacco, N. (2008). "Optimisation of fresh-food supply chains in uncertain environments, Part II: A case study". Biosystems Engineering, 99(3) PP: 360-371.

Das, C. and Tyagi, R. (1997). "Role of inventory and transportation costs in determining the optimal degree of centralization". Transportation Research Part E: Logistics and Transportation Review, 33(3) PP: 171-179.

Daskin, M. (1997). Network and discrete location: models, algorithms and applications, New York, John Wiley and sons Inc.

Daskin, M. S., Coullard, C. R. and Shen, Z. J. M. (2002). "An inventory-location model: formulation, solution algorithm and computational results". Annals of Operations Research, 110(1-4) PP: 83-106.

Diabat, A., Aouam, T. and Ozsen, L. (2009). "An evolutionary programming approach for solving the capacitated facility location problem with risk pooling". International Journal of Applied Decision Sciences, 2(4) PP: 389-405.

Diabat, A., Richard, J. P. and Codrington, C. W. (2013). "A Lagrangian relaxation approach to simultaneous strategic and tactical planning in supply chain design". Annals of Operations Research, 203(1) PP: 55-80.

Drezner, Z. and Scott, C. H. (2013). "Location of a distribution center for a perishable product". Mathematical Methods of Operations Research, 78(3) PP: 301-314.

Eppen, G. D. (1979). "Effects of Centralization on Expected Costs in a Multi-Location Newsboy Problem". Management Science, 25(5) PP: 498-501.

Erlebacher, S. J. and Meller, R. D. (2000). "The interaction of location and inventory in designing distribution systems". IIE Transactions, 32(2) PP: 155 - 166.

Eskigun, E., Uzsoy, R., Preckel, P. V., Beaujon, G., Krishnan, S. and Tew, J. D. (2005). "Outbound supply chain network design with mode selection, lead times and capacitated vehicle distribution centers". European Journal of Operational Research, 165(1) PP: 182-206.

Faccio, M., Persona, A., Sgarbossa, F. and Zanin, G. (2011). "Multi-stage supply network design in case of reverse flows: A closed-loop approach". International Journal of Operational Research, 12(2) PP: 157-191.

Fathali, J. (2006). "A genetic algorithm for the p-median problem with pos/neg weights". Applied Mathematics and Computation, 183(2) PP: 1071-1083.

Ferguson, M. and Ketzenberg, M. E. (2006). "Information sharing to improve retail product freshness of perishables". Production and Operations Management, 15(1) PP: 57-73.

Fisher, M. L. (1985). "Applications oriented guide to Lagrangian relaxation". Interfaces, 15(2) PP: 10-21.

Gaur, S. and Ravindran, A. R. (2006). "A bi-criteria model for the inventory aggregation problem under risk pooling". Computers and Industrial Engineering, 51(3) PP: 482-501.

Gebennini, E., Gamberini, R. and Manzini, R. (2009). "An integrated production-distribution model for the dynamic location and allocation problem with safety stock optimization". International Journal of Production Economics, 122(1) PP: 286-304.

Geoffrion, A. and Bride, R. M. (1978). "Lagrangean relaxation applied to capacitated facility location problems". AIIE transactions, 10(1) PP: 40-47.

Gerchak, Y. and He, Q. M. (2003). "On the relation between the benefits of risk pooling and the variability of demand". IIE Transactions (Institute of Industrial Engineers), 35(11) PP: 1027-1031.

Gharegozloo Hamedani, S., Saeed Jabalameli, M. and Bozorgi-Amiri, A. (2013). "A location-inventory model for distribution centers in a three-level supply chain under uncertainty". International Journal of Industrial Engineering Computations, 4(1) PP: 93-110.

Ghezavati, V. R., Jabal-Ameli, M. S. and Makui, A. (2009). "A new heuristic method for distribution networks considering service level constraint and coverage radius". Expert Systems with Applications, 36(3 PART 1) PP: 5620-5629.

Ghosh, D. (2003). "Neighborhood search heuristics for the uncapacitated facility location problem". European Journal of Operational Research, 150(1) PP: 150-162.

Goyal, S. K. and Giri, B. C. (2001). "Recent trends in modeling of deteriorating inventory". European Journal of Operational Research, 134(1) PP: 1-16.

Guerrero, W. J., Prodhon, C., Velasco, N. and Amaya, C. A. (2013). "Hybrid heuristic for the inventory location-routing problem with deterministic demand". International Journal of Production Economics, 146(1) PP: 359-370.

Gürler, Ü. and Özkaya, B. Y. (2008). "Analysis of the (s, S) policy for perishables with a random shelf life". IIE Transactions, 40(8) PP: 759-781.

Haijema, R., Van Der Wal, J. and Van Dijk, N. M. (2007). "Blood platelet production: Optimization by dynamic programming and simulation". Computers & Operations Research, 34(3) PP: 760-779.

Hasani, A., Zegordi, S. H. and Nikbakhsh, E. (2011). "Robust closed-loop supply chain network design for perishable goods in agile manufacturing under uncertainty". International Journal of Production Research, 50(16) PP: 4649-4669.

Haupt, R. L. and Haupt, S. E. (2004). Practical genetic algorithms, New York, Wiley-Interscience.

Held, M. and Karp, R. M. (1970). "The traveling-salesman problem and minimum spanning trees". Operations Research, 18(6) PP: 1138-1162.

Hinojosa, Y., Kalcsics, J., Nickel, S., Puerto, J. and Velten, S. (2008). "Dynamic supply chain design with inventory". Computers and Operations Research, 35(2) PP: 373-391.

Holmberg, K., Rönnqvist, M. and Yuan, D. (1999). "An exact algorithm for the capacitated facility location problems with single sourcing". European Journal of Operational Research, 113(3) PP: 544-559.

Hsu, C. I., Hung, S. F. and Li, H. C. (2007). "Vehicle routing problem with time-windows for perishable food delivery". Journal of Food Engineering, 80(2) PP: 465-475.

Imai, A., Nishimura, E. and Current, J. (2007). "A Lagrangian relaxation-based heuristic for the vehicle routing with full container load". European Journal of Operational Research, 176(1) PP: 87-105.

Jeet, V., Kutanoglu, E. and Partani, A. (2009). "Logistics network design with inventory stocking for low-demand parts: Modeling and optimization". IIE Transactions (Institute of Industrial Engineers), 41(5) PP: 389-407.

Jia, J. and Hu, Q. (2011). "Dynamic ordering and pricing for a perishable goods supply chain". Computers & Industrial Engineering, 60(2) PP: 302-309.

Jourdan, L., Basseur, M. and Talbi, E. G. (2009). "Hybridizing exact methods and metaheuristics: A taxonomy". European Journal of Operational Research, 199(3) PP: 620-629.

Kanchanasuntorn, K. and Techanitisawad, A. (2006). "An approximate periodic model for fixed-life perishable products in a two-echelon inventory-distribution system". International Journal of Production Economics, 100(1) PP: 101-115.

Kang, J. H. and Kim, Y. D. (2012). "Inventory control in a two-level supply chain with risk pooling effect". International Journal of Production Economics, 135(1) PP: 116-124.

Kim, Y.-J., Kim, C.-S. and Hwang, H. (2003). "An inventory model for perishable items with stock-dependent-demand rate under mixed issuing policy". Asia Pacific Management Review, 8(4) PP: 509-522.

Klose, A. and Drexl, A. (2005). "Facility location models for distribution system design". European Journal of Operational Research, 162(1) PP: 4-29.

Kouki, C., Jemai, Z., Sahin, E. and Dallery, Y. (2013a). "Analysis of a periodic review inventory control system with perishables having random lifetime". International Journal of Production Research, 52(1) PP: 283-298.

Kouki, C., Sahin, E., Jemaï, Z. and Dallery, Y. (2013b). "Assessing the impact of perishability and the use of time temperature technologies on inventory management". International Journal of Production Economics, 143(1) PP: 72-85.

Kumar, S. K. and Tiwari, M. K. (2013). "Supply chain system design integrated with risk pooling". Computers & Industrial Engineering, 64(2) PP: 580-588.

Li, J., Chu, F. and Prins, C. (2009). "Lower and upper bounds for a capacitated plant location problem with multicommodity flow". Computers & Operations Research, 36(11) PP: 3019-3030.

Liao, S., Hsieh, C. and Lin, Y. (2011a). "A multi-objective evolutionary optimization approach for an integrated location-inventory distribution network problem under vendor-managed inventory systems". Annals of Operations Research, 186(1) PP: 213-229.

Liao, S. H., Hsieh, C. L. and Lai, P. J. (2011b). "An evolutionary approach for multi-objective optimization of the integrated location-inventory distribution network problem in vendor-managed inventory". Expert Systems with Applications, 38(6) PP: 6768-6776.

Lin, J. R., Nozick, L. K. and Turnquist, M. A. (2006). "Strategic design of distribution systems with economies of scale in transportation". Annals of Operations Research, 144(1) PP: 161-180.

Liu, S. C. and Lee, S. B. (2003). "A two-phase heuristic method for the multi-depot location routing problem taking inventory control decisions into consideration". International Journal of Advanced Manufacturing Technology, 22(11-12) PP: 941-950.

Liu, S. C. and Lin, C. C. (2005). "A heuristic method for the combined location routing and inventory problem". International Journal of Advanced Manufacturing Technology, 26(4) PP: 372-381.

Lübbecke, M. E. and Desrosiers, J. (2005). "Selected topics in column generation". Operations Research, 53(6) PP: 1007-1023.

Mak, H. Y. and Shen, Z. J. M. (2009). "A two-echelon inventory-location problem with service considerations". Naval Research Logistics, 56(8) PP: 730-744.

Max Shen, Z.-J. and Qi, L. (2007). "Incorporating inventory and routing costs in strategic location models". European Journal of Operational Research, 179(2) PP: 372-389.

Melkote, S. and Daskin, M. S. (2001a). "Capacitated facility location/network design problems". European Journal of Operational Research, 129(3) PP: 481-495.

Melkote, S. and Daskin, M. S. (2001b). "An integrated model of facility location and transportation network design". Transportation Research Part A: Policy and Practice, 35(6) PP: 515-538.

Melo, M. T., Nickel, S. and Saldanha-Da-Gama, F. (2009). "Facility location and supply chain management - A review". European Journal of Operational Research, 196(2) PP: 401-412.

Melo, M. T., Nickel, S. and Saldanha-Da-Gama, F. (2012). "A tabu search heuristic for redesigning a multi-echelon supply chain network over a planning horizon". International Journal of Production Economics, 136(1) PP: 218-230.

Min, H. and Zhou, G. (2002). "Supply chain modeling: past, present and future". Computers & Industrial Engineering, 43(1–2) PP: 231-249.

Minner, S. and Transchel, S. (2010). "Periodic review inventory-control for perishable products under service-level constraints". OR Spectrum, 32(4) PP: 979-996.

Miranda, P. A. and Garrido, R. A. (2004). "Incorporating inventory control decisions into a strategic distribution network design model with stochastic demand". Transportation Research Part E: Logistics and Transportation Review, 40(3) PP: 183-207.

Miranda, P. A. and Garrido, R. A. (2006). "A simultaneous inventory control and facility location model with stochastic capacity constraints". Networks and Spatial Economics, 6(1) PP: 39-53.

Miranda, P. A. and Garrido, R. A. (2008). "Valid inequalities for Lagrangian relaxation in an inventory location problem with stochastic capacity". Transportation Research Part E: Logistics and Transportation Review, 44(1) PP: 47-65.

Miranda, P. A. and Garrido, R. A. (2009). "Inventory service-level optimization within distribution network design problem". International Journal of Production Economics, 122(1) PP: 276-285.

Mohammadi Bidhandi, H., Mohd. Yusuff, R., Megat Ahmad, M. M. H. and Abu Bakar, M. R. (2009). "Development of a new approach for deterministic supply chain network design". European Journal of Operational Research, 198(1) PP: 121-128.

Nahmias, S. (1982). "Perishable Inventory Theory: A Review". Operations Research, 30(4) PP: 680-708.

Naseraldin, H. and Herer, Y. T. (2011). "A location-inventory model with lateral transshipments". Naval Research Logistics, 58(5) PP: 437-456.

Nowak, I. (2006). Relaxation and decomposition methods for mixed integer nonlinear programming, Birkhäuser Basel, Boston.

Nozick, L. K. and Turnquist, M. A. (1998). "Integrating inventory impacts into a fixed-charge model for locating distribution centers". Transportation Research Part E: Logistics and Transportation Review, 34E(3) PP: 173-186.

Nozick, L. K. and Turnquist, M. A. (2001). "Inventory, transportation, service quality and the location of distribution centers". European Journal of Operational Research, 129(2) PP: 362-371.

Olsson, F. and Tydesjö, P. (2010). "Inventory problems with perishable items: Fixed lifetimes and backlogging". European Journal of Operational Research, 202(1) PP: 131-137.

Omosigho, S. E. (2002). "Determination of outdate and shortage quantities in the inventory problem with fixed lifetime". International Journal of Computer Mathematics, 79(11) PP: 1169-1177.

Ozsen, L., Coullard, C. R. and Daskin, M. S. (2008). "Capacitated warehouse location model with risk pooling". Naval Research Logistics, 55(4) PP: 295-312.

Ozsen, L., Daskin, M. S. and Coullard, C. R. (2009). "Facility location modeling and inventory management with multisourcing". Transportation Science, 43(4) PP: 455-472.

Park, S., Lee, T.-E. and Sung, C. S. (2010). "A three-level supply chain network design model with risk-pooling and lead times". Transportation Research Part E: Logistics and Transportation Review, 46(5) PP: 563-581.

Pedersen, S. G., Zachariassen, F. and Arlbjørn, J. S. (2012). "Centralisation vs de-centralisation of warehousing: A small and medium-sized enterprise perspective". Journal of Small Business and Enterprise Development, 19(2) PP: 352-369.

Pirlot, M. (1996). "General local search methods". European Journal of Operational Research, 92(3) PP: 493-511.

Punakivi, M. and Hinkka, V. (2006). "Selection criteria of transportation mode: A case study in four finnish industry sectors". Transport Reviews, 26(2) PP: 207-219.

Qi, L. and Shen, Z. J. M. (2007). "A supply chain design model with unreliable supply". Naval Research Logistics, 54(8) PP: 829-844.

Ramaekers, K. (2009). "A simulation optimisation approach for inventory management decision support based on incomplete information". 4OR, 7(1) PP: 93-96.

Romeijn, H. E., Shu, J. and Teo, C.-P. (2007). "Designing two-echelon supply networks". European Journal of Operational Research, 178(2) PP: 449-462.

Rosing, K. E. and Hodgson, M. J. (2002). "Heuristic concentration for the p-median: an example demonstrating how and why it works". Computers & Operations Research, 29(10) PP: 1317-1330.

Sahinidis, N. V. (2004). "Optimization under uncertainty: state-of-the-art and opportunities". Computers & Chemical Engineering, 28(6) PP: 971-983.

Sajjadi, S. R. and Cheraghi, S. H. (2011). "Multi-products location-routing problem integrated with inventory under stochastic demand". International Journal of Industrial and Systems Engineering, 7(4) PP: 454-476.

Schilling, D. A., Jayaraman, V. and Barkhi, R. (1993). "A review of covering problems in facility location". Location Science, 1(1) PP: 25-55.

Shahabi, M., Akbarinasaji, S., Unnikrishnan, A. and James, R. (2013). "Integrated Inventory Control and Facility Location Decisions in a Multi-Echelon Supply Chain Network with Hubs". Networks and Spatial Economics, 13(4) PP: 497-514.

Shavandi, H. and Bozorgi, B. (2012). "Developing a location-inventory model under fuzzy environment". International Journal of Advanced Manufacturing Technology, 63(1-4) PP: 191-200.

Shen, Z. J. M. (2005). "A multi-commodity supply chain design problem". IIE Transactions (Institute of Industrial Engineers), 37(8) PP: 753-762.

Shen, Z. J. M. (2007). "Integrated supply chain design models: A survey and future research directions". Journal of Industrial and Management Optimization, 3(1) PP: 1-27.

Shen, Z. J. M., Coullard, C. and Daskin, M. S. (2003). "A joint location-inventory model". Transportation Science, 37(1) PP: 40-55.

Shetty, B. (1990). "Approximate solutions to large scale capacitated facility location problems". Applied Mathematics and Computation, 39(2) PP: 159-175.

Shu, J. (2010). "An efficient greedy heuristic for warehouse-retailer network design optimization". Transportation Science, 44(2) PP: 183-192.

Shu, J., Li, Z., Shen, H., Wu, T. and Zhong, W. (2012). "A logistics network design model with vendor managed inventory". International Journal of Production Economics, 135(2) PP: 754-761.

Shu, J., Ma, Q. and Li, S. (2010). "Integrated location and two-echelon inventory network design under uncertainty". Annals of Operations Research, 181(1) PP: 233-247.

Shu, J., Teo, C. P. and Shen, Z. J. M. (2005). "Stochastic transportation-inventory network design problem". Operations Research, 53(1) PP: 48-60.

Snyder, L. V. (2006). "Facility location under uncertainty: a review". IIE Transactions, 38(7) PP: 547-564.

Snyder, L. V., Daskin, M. S. and Teo, C. P. (2007). "The stochastic location model with risk pooling". European Journal of Operational Research, 179(3) PP: 1221-1238.

Sourirajan, K., Ozsen, L. and Uzsoy, R. (2007). "A single-product network design model with lead time and safety stock considerations". IIE Transactions (Institute of Industrial Engineers), 39(5) PP: 411-424.

Sourirajan, K., Ozsen, L. and Uzsoy, R. (2009). "A genetic algorithm for a single product network design model with lead time and safety stock considerations". European Journal of Operational Research, 197(2) PP: 599-608.

Stevenson, W. J. (2008). Operations Management, Mc Graw Hill, New York.

Teo, C. P., Ou, J. and Goh, M. (2001). "Impact on inventory costs with consolidation of distribution centers". IIE Transactions, 33(2) PP: 99 - 110.

Teo, C. P. and Shu, J. (2004). "Warehouse-retailer network design problem". Operations Research, 52(3) PP:

Tsai, J.-F. (2007). "An optimization approach for supply chain management models with quantity discount policy". Eur. J. Oper. Res., 177(2) PP: 982-994.

Tsao, Y. C. and Lu, J. C. (2012). "A supply chain network design considering transportation cost discounts". Transportation Research Part E: Logistics and Transportation Review, 48(2) PP: 401-414.

Tsao, Y. C., Mangotra, D., Lu, J. C. and Dong, M. (2012). "A continuous approximation approach for the integrated facility-inventory allocation problem". European Journal of Operational Research, 222(2) PP: 216-228.

Tuzun, D. and Burke, L. I. (1999). "Two-phase tabu search approach to the location routing problem". European Journal of Operational Research, 116(1) PP: 87-99.

Üster, H., Keskin, B. B. and Çetinkaya, S. (2008). "Integrated warehouse location and inventory decisions in a three-tier distribution system". IIE Transactions, 40(8) PP: 718-732.

Vidyarthi, N., Çelebi, E., Elhedhli, S. and Jewkes, E. (2007). "Integrated production-inventory-distribution system design with risk pooling: Model formulation and heuristic solution". Transportation Science, 41(3u) PP: 392-408.

Who (2011). "Global database on blood safety, summary report 2011". World Health Organization <http://www.who.int/bloodsafety/global_database/GDBS_Summary_Report_2011.pdf>. Accessed 07.02.2013.,

Wu, T. and Zhang, K. (2014). "A computational study for common network design in multi-commodity supply chains". Computers and Operations Research, 44(2014) PP: 206-213.

Zheng, Y.-S. (1992). "On Properties of Stochastic Inventory Systems". Management Science, 38(1) PP: 87-103.