



THE UNIVERSITY

of ADELAIDE

EVOLUTIONARY ALGORITHMS FOR SUPPLY CHAIN OPTIMISATION

Maksud Ibrahimov

Submitted in fulfillment of the requirements
of the degree of Doctor of Philosophy

Principal Supervisor: Professor Zbigniew Michalewicz
Co Supervisor: Dr. Arvind Mohais
Co Supervisor: Dr. Charles Lakos

October 2012
School of Computer Science
The University of Adelaide
Australia

Contents

List of Figures	1
List of Tables	4
Abstract	5
Thesis Declaration	7
1 Introduction	15
1.1 Motivation	15
1.2 Theory and practice of evolutionary algorithms	16
1.3 Objectives	20
1.4 Organisation	24
1.5 Publications	25
2 Basic Concepts and Literature Review	29
2.1 Supply Chain Management	30
2.2 Global Optimisation	35
2.3 Evolutionary Algorithms	40
2.3.1 Structure of the Evolutionary Algorithm	41
2.3.2 Variants of Evolutionary Algorithms	43
2.4 Scheduling	47
2.5 Vehicle Routing Problem	49
2.6 Coevolution	53
2.7 Summary	54
3 Single Silo Model	57
3.1 Introduction	58
3.2 Dynamic Optimisation Problems	59
3.2.1 Time-varying objective functions	60
3.2.2 Time-varying input variables	61
3.2.3 Time-varying constraints	62
3.3 Problem	63
3.4 Time-Varying Challenges in Wine Bottling	69
3.5 The Solution Using an Evolutionary Algorithm.	74

3.5.1	Representation	75
3.5.2	Decoding	76
3.5.3	Operators	77
3.5.4	Solving the Dynamic Issues	79
3.6	Summary	82
4	Two-silo Supply Chain	85
4.1	The Problem	85
4.2	Algorithms	87
4.2.1	Algorithm for the JSSP	87
4.2.2	Algorithm for the VRP	90
4.2.3	Sequential Approach	92
4.2.4	Cooperative Coevolutionary Approach	92
4.2.5	Cooperative Coevolution with Non-dominated Parent Selection	94
4.2.6	Cooperative Approach with On-the-fly Partner Generation	95
4.3	Experiments and Results	96
4.3.1	Optimal Parameter Setting in the Two-silo Experiment	99
4.4	Summary	101
5	Two-echelon Multi-silo Supply Chain	103
5.1	Two-echelon Experimental Model	104
5.1.1	Introduction	104
5.1.2	Problem	106
5.1.3	Simulation Framework	107
5.1.4	Algorithm	108
5.1.5	Experiments and Results	111
5.2	Two-echelon Case Study	113
5.2.1	Problem	113
5.2.2	Solution	117
5.2.3	Experiments and Results	124
5.3	Summary	126
6	Two-echelon Multi-silo Real-world Case Study	129
6.1	Basic Concepts and Literature Review	129
6.2	Problem Description	133
6.2.1	Constraints and Business Rules	135
6.2.2	Overall Objectives	137
6.3	The Model	138
6.3.1	Supply Chain Model	138
6.3.2	General Notations	139
6.3.3	Objectives of the Optimiser	140
6.3.4	Constraints	141
6.4	Approach	142
6.4.1	Structure of a Solution	142
6.4.2	The Quality Score of the Solution	143

6.4.3	The Optimiser	143
6.5	Results	146
6.6	Functionality	150
6.6.1	Hierarchy Tab	150
6.6.2	Map Tab	151
6.6.3	Configuration Tab	152
6.6.4	Optimisation Tab	155
6.6.5	Dashboard Tab	157
6.6.6	What-if Functionality	157
6.7	Summary	158
7	Multi-echelon Supply Chain	159
7.1	Wine Supply Chain	159
7.1.1	Maturity Models	162
7.1.2	Vintage Intake Planning	163
7.1.3	Crushing	163
7.1.4	Tank Farm	164
7.1.5	Bottling	164
7.2	Vintage Intake Planning	165
7.2.1	Description of the Problem	165
7.2.2	Constraints	166
7.3	Tank Farm	168
7.3.1	Description of the Problem	169
7.3.2	Functionality	171
7.3.3	Results	174
7.4	Algorithm for the Global Module	176
7.4.1	Algorithm	176
7.4.2	System Design and Communication Protocol	178
7.4.3	Results	180
7.5	Summary	180
8	Multi-silo Supply Chain with Complex Structure	183
8.1	Introduction	183
8.2	The Problem	185
8.3	Related Work	187
8.4	The Approach	190
8.4.1	The Supply Chain Model	190
8.4.2	Features of the Optimiser	194
8.4.3	Event-Based Optimisation	195
8.4.4	Rule-Based Optimisation	198
8.5	Experimental Results	203
8.6	Summary	206
9	Concluding Remarks and Future Work	209
9.1	Main contributions	209
9.2	Future work	212

List of Figures

1.1	Packing of water tanks into the truck. The top picture presents the side view, the bottom presents the top view of the truck.	18
1.2	A single silo.	21
1.3	Two-silo model.	21
1.4	Two-echelon model with a single silo in each echelon.	22
1.5	Two-echelon models.	22
1.6	Two-echelon extended model	23
1.7	Five-echelon model	23
1.8	Multi-echelon supply chain with complex structure	23
2.1	Schematic view of multi-echelon supply chain network	31
2.2	Wine Supply Chain. Grey arrows on this diagram represent a material flow. Black arrows represent information flow. The dotted components represent external components to the company	35
3.1	Typical Issues in Real-World Problems	63
3.2	The Wine Bottling Process	64
3.3	Visualisation of a schedule on multiple production lines in the software application	69
3.4	Machine Availability Interface	70
3.5	Material Requirements Interface	70
3.6	Manual Assignment Interface	72
3.7	Freeze Period Illustration	74
3.8	Scheduling Individual Representation	75
3.9	A Time Block Node	76
3.10	Illustration of the Decoding Process	77
3.11	Modified Initial Time Blocks for Manual Locks	80

3.12	Realigning a Solution	81
4.1	Simulated two-silo supply chain	86
4.2	Partially mapped crossover (PMX)	89
4.3	Insertion mutation	89
4.4	Inversion mutation	89
4.5	Swap mutation	90
4.6	Order crossover (OX)	91
4.7	Solutions produced by cooperative coevolutionary approach . . .	100
4.8	Solutions produced by sequential approach	100
4.9	3D grid for parameter setting	101
5.1	Simulated two-echelon supply chain with many-to-one flow . . .	105
5.2	Simulated two-echelon supply chain with one-to-many flow . . .	105
5.3	A roll of sheet steel.	114
5.4	(a) Batching of orders into a single roll. (b) Wastage resulting from the batching process. 4 rolls of 600mm, and 2 of 500mm needed.	116
5.5	Two-echelon multi-silo supply chain with one-to-one dependen- cies between components	117
5.6	Steel optimiser's main screen.	118
5.7	First part of the representation of an individual.	119
5.8	Second part of the representation of an individual.	119
5.9	Sample run. Profit over generations.	125
5.10	Sample run. Penalty function over generations.	126
6.1	Product movement for mine planning.	134
6.2	Mining supply chain with inter- and intra-echelon interactions . .	138
6.3	Result of the optimiser.	147
6.4	Result of the optimiser. Quality of the first objective with the limited truck capacity.	148
6.5	Result of the optimiser. Tonnage graph with the limited truck capacity.	148
6.6	Result of the optimiser. Tonnage graph.	149
6.7	Result of the optimiser. Graph of quality of Iron.	149
6.8	Result of the optimiser. Graph of quality of Silicon.	150
6.9	Screenshot presents the hierarchy tab with coordinates and ton- nages of a selected block and its dependencies.	151

6.10 Screenshot presents the 3D view of the mine and map controls. . . 152

6.11 Screenshot presents the configuration tab. 154

6.12 Screenshot presenting the dynamic configuration by time period
tab. 156

6.13 Screenshot of the optimisation tab with the performance graphs
and detailed schedule. 156

6.14 Screenshot of the dashboard tab. 157

7.1 Wine Supply Chain. Grey arrows on this diagram represent a
material flow. Black arrows represent information flow. 161

7.2 Grape Flow at intake. Note that not all grape processing steps
within a winery are mandatory. 167

7.3 Screenshot of the Vintage Intake Planning System 167

7.4 Tank Farm Map View Screenshot. The circles represent physical
layout and contents (by colour). An Activities popup shows the
transactions on a single tank 171

7.5 Tank Farm Table View Screenshot. Timelines for the tanks are
visible on the right, coloured by the wine variety 173

7.6 The design of the wine supply chain with global optimisation . . 178

8.1 Simple supply chain example to demonstrate complexity of bal-
ancing the components involved. 186

8.2 Diagram, configuration and production details of the supply chain 187

8.3 Supply Chain model showing material flow between supply chain
nodes 191

8.4 Supply Chain illustrating material flow routed by Switches . . . 192

8.5 Timeline of the simulated horizon illustrating the impact of the
date mutation operator on the event queue (dashed lines indicate
the time events occur, i.e. when their they cause a change of the
state of the simulated system). 197

8.6 Overlay of 5 membership functions denoting the fill level of a
tank. At a level of 740l, the tank level is a member of the “low”
function by 0.15 and a member of the “medium” function by 0.85.
For each storage, the parameters for each membership function
are different as the maximum capacity may differ (and hence
”very high” would relate to a different maximal level). 200

8.7	Encoding the rule bases. Elements in squares are of type integer number and stand either for booleans or indices in look-up-tables that hold linguistic variables and values.	201
8.8	Impact of mutation on decoded phenotype (“-1” means the term is not considered in the rule)	202
8.9	Total product yield of event-based and rule-based approach . . .	204
8.10	Decline of total yield when optimising periods in isolation	206

List of Tables

4.1	Run results of the two-silo experiment	99
5.1	Run results of the multi-silo experimental supply chain	112
5.2	(a) Demand table: The quantity of each item ordered by each customer. (b) Production capacity table: Tonnes per hour production rates of each plant for different products.	115
6.1	Solution representation	143

Abstract

Many real-world problems can be modelled as a combination of several interacting components. Methods based on Evolutionary Algorithms seem to be appropriate for handling such problems, but they have not been extensively researched in such domains. In this thesis we study the applicability of Evolutionary Algorithms for today's high complexity real-world problems which consist of several interacting components. A natural source of such problems emerged from supply chain management problems which consist of several interacting components, and are also generally non-linear, heavily constrained, and involve many variables. We aim to study possible approaches for supply chain optimisation problems that seamlessly integrate algorithms addressing the local components, under the framework of global optimisation.

Thesis Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide.

I give consent to this copy of my thesis, when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library catalogue, and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

Dedication

To my parents and my sister Nargiz.

Acknowledgements

I would like to thank my supervisory panel comprising of Prof. Zbigniew Michalewicz, Dr. Arvind Mohais and Dr. Charles Lakos for their support throughout the candidature. I especially want to acknowledge the support and guidance of my primary supervisor, Prof. Zbigniew Michalewicz. I was extremely fortunate to meet him, he has not only been the greatest mentor who inspired me and provided his invaluable insight into the field of evolutionary computation and its connection with business but also is a true role model for me. I would like to also mention help and support of Dr. Arvind Mohais. His guidance helped me to deeply understand many aspects of evolutionary computation.

Great credit is due to Matthew Michalewicz, Constantin Chiriac, Roland Spitty and Dr. Luigi Barone for their wise advices on different aspects of business, supply chain and software development. Additionally, I would like to thank support and help of Dr. Larisa Aksenova who supported me immeasurably.

I cannot thank enough my parents and my sister for their love and support. I also thank William Winser for his assistance with proof-reading the text.

