ENHANCING GENETIC ALGORITHMS BASED SOLUTIONS FOR MULTI SOURCE FLEXIBLE MULTISTAGE LOGISTICS NETWORK MODELS

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Computer Science)

Faculty of Computer Science and Information System
Universiti Teknologi Malaysia

JUNE 2012

Dedicated to…

My beloved father; "Shaban Bozorgi Rad" and also to my beloved mother; "Tarane Zare"

for their continued love, guidance and support throughout my life.

Love you always.

I could have never done it without you.

Love you always.

Thanks for showering me with love, support and encouragement.

Life has been wonderfully colored by both of you.

ACKNOWLEDGEMENT

In the name of Allah the Most Gracious and the Most Merciful, I thank Thee with all my heart for granting Thy Servant immeasurable help during the course of this study and peace be upon him, the last messenger of Allah.

Firstly, I would like to express my deepest gratitude to my supervisors, Prof. Dr. Mohammad Ishak Desa and Dr. Antoni Wibowo for their encouragement, continuous support and guidance while completing this work. Their views, practical guidance and constructive comments were proven to be extremely valuable. Secondly, I would like to express my gratitude to Universiti Technologi Malaysia and Ministry of Higher Education (MOHE) Malaysia for sponsoring this research under FRGS (Vot. 78502), and all the staff from Department of Modeling and Industrial Computing, for their support with both time and energy.

Finally, special thanks to all the members of my family for their warm encouragement and love in carrying me through the challenging times throughout this study. I would like to acknowledge each person who has contributed to the success of this report, whether directly or indirectly. May Allah s.w.t prolong the lives of these people and reward them in the best possible way. Amin.

ABSTRACT

A multistage logistics network problem deals with determining the optimal routes for product delivery to customers through a network of multiple facilities namely plants, distribution centers and retailers. The optimal routes should maximize revenues or minimize costs to a business or logistics provider. The flexible multistage logistics network (fMLN) problem is an extension of the traditional multistage logistics network whereby a customer can procure goods directly from plants or distribution centers needless of retailers. It is well known that fMLN problem is NP-hard, thus, it requires, for a large size problem, a non-polynomial time to solve analytically. In addition, an fMLN problem usually involves optimization that has a large number of constraints and decision variables. Previous researchers have attempted to use soft computing approaches namely Genetic Algorithms (GA) to address the fMLN problem. In terms of modeling, previous research considered fMLN problem with single source assumption, whereby each customer would be served by only one facility. In reality, a customer may be served by a number of facilities or by multi source and can order a number of different products. Besides that, business or logistics provider is required not only to minimize the total logistics costs but also other criteria such as the total delivery time simultaneously. Under these circumstances, the fMLN problem becomes more complex, and the standard GA could not perform reasonably well due to a decreasing the quality of solution. In this research a single source fMLN problem is extended to cater for multi source, multi product and multi objective fMLN cases. It is proven that the standard GA and the previous chromosome representation could not be used to solve the extended fMLN problems. Here, two new chromosome representations were proposed and implemented on GA with penalty method. In addition, heuristic rules were developed and embedded into GA to cope with the constraints in the fMLN problems. The experimental results showed that the proposed chromosome representations and the heuristic rules have substantially improved the GA performance in terms of running time and solution quality for the extended fMLN problems.

ABSTRAK

Masalah rangkaian logistik berperingkat, secara lazimnya, menentukan laluan terbaik bagi penghantaran produk kepada pengguna melalui rangkaian pelbagai kemudahan yang terdiri dari kilang, pusat pengagihan serta peruncit. Laluan-laluan terbaik ini sepatutnya meningkatkan pendapatan pada tahap maksima, atau mengurangkan kos pada tahap minima kepada perniagaan ataupun pembekal logistik. Masalah rangkaian logistik bolehubah berperingkat (fMLN) merupakan lanjutan kepada rangkaian logistik berperingkat tradisional, di mana sesaorang pengguna boleh membeli barangan secara terus dari kilang-kilang atau pusat-pusat pengagihan, tanpa melalui pihak peruncit. Sudah menjadi ketahuan bahawa masalah fMLN adalah 'NP-hard'. Oleh sebab itu, ia memerlukan algoritma bukan berpolinomial bagi menyelesaikan masalah ini. Tambahan pula, masalah fMLN ini juga melibatkan pengoptimuman dengan kekangan dan pembolehubah keputusan yang banyak. Maka, para penyelidik terdahulu telah mencuba untuk menggunakan pendekatan "soft-computing", terutamanya Algoritma Genetik (GA) untuk menyelesaikan masalah tersebut. Dari segi pemodelan, para penyelidik terdahulu telah mengambil kira masalah fMLN dengan andaian sumber tunggal, iaitu sesaorang pengguna hanya boleh dilayan oleh satu kemudahan sahaja. Walau bagaimanapun, secara realiti, sesaorang pengguna sepatutnya boleh dilayan oleh beberapa kemudahan atau lebih dikenali sebagai sumber pelbagai, dan juga boleh membeli sebilangan jenis barangan mengikut kehendak pengguna tersebut. Tambahan pula, suatu perniagaan atau pembekal logistik boleh bukan sahaja meminimakan jumlah kos logistik tetapi juga perlu, dalam masa yang sama, meminimakan kriteria yang lain, misalnya keseluruhan masa penghantaran. Dalam keadaan sedemikian, masalah fMLN menjadi lebih kompleks dan GA yang biasa, tidak dapat menyelesaikanya dengan baik. Dalam penyelidikan ini, masalah fMLN bersumber tunggal telah dikembangkan untuk memenuhi keperluan kes-kes fMLN bersumber pelbagai, berproduk pelbagai dan berobjektif pelbagai. Ia telah terbukti bahawa GA yang biasa, dan perwakilan kromosom terdahulu, tidak dapat digunakan untuk menyelesaikan masalah fMLN lanjutan tersebut. Di sini, dua perwakilan kromosom baru telah dicadangkan dan dilaksanakan ke atas GA dengan kaedah penalti. Selain itu, peraturan heuristik telah dibentuk dan diserapkan ke dalam GA untuk menangani masalah kekangan dalam model fMLN tersebut. Keputusan ujikaji telah menunjukkan bahawa perwakilan kromosom yang telah dicadangkan, serta peraturan-peraturan heuristik yang dibangunkan telah dapat meningkatkan prestasi GA dengan ketara dari segi tempoh perlaksanaan serta kualiti penyelesaian bagi masalah fMLN lanjutan tersebut.

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LIST OF ABBREVIATIONS

fMLN	-	Flexible Multistage Logistics Network
bTP	-	Bi-Criteria Transportation Problem
CSPs	-	Constraint Satisfaction Problems
GA	-	Genetic Algorithms
DC	-	Distribution Center
NP-hard	-	Non Deterministic Polynomial Time Hard
EAs	-	Evolutionary Algorithms
escTP	-	Exclusionary Side Constraint Transportation Problem
SCM	-	Supply Chain Management
TP	-	Transportation Problem
mIP	-	Mixed Integer Programming
tMLN	-	Traditional Multistage Logistics Network
COPs	-	Combinatorial Optimization Problems
hEA	-	Hybrid Evolutionary Algorithm
SCN	-	Supply Chain Network
PSO	-	Particle Swarm Optimization
mrLNP	-	Multi-Stage Reverse Logistics Network Problem
mt-PDI	-	Multi-Time Period Production/Distribution And Inventory Problem
P-GA	-	Genetic Algorithm with Penalty Methods (Penalty GA)
HR-GA	-	P-GA with Heuristics Rules (Heuristics Rules Based GA)
RB-GA	-	Route Based GA

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Logistic optimization has become an increasingly important component of supply chain management in improving business efficiency in agile and global manufacturing. Nowadays in the competitive market environment, minimizing the cost of transportation and other related costs within logistic network while considering the minimization of the total product delivery time are the key factors for success.

Comprehensive logistic systems encompass entire processes from transportation of raw material and input requirements of supplier to plant, the processing input to product at plant, transport to warehouse/facility, and delivery to end user. The effective management of logistics systems demands the input of dynamic and static flow conditions, transportation and storage. This has turned the primary focus of the market on the efficient management of logistics systems. This explains the complexity of modern logistic network designs, in light of detailed considerations for business entities, more so of the multinational types. Nevertheless, optimization proves complicated with the complexities of logistic networks, in spite of the strong demand for cost reduction in logistics (Gen *et al*., 2008).

The logistics network design problem defined by Vidal and Dogan, (2002) comprises of the need to maximize revenue, minimize cost, by determining optimal production-distribution configurations between company subchapters with the inputs of potential suppliers, potential production facilities, and distribution centers with multiple configuration possibilities, and customers with deterministic demands, to meet service requirements.

Existing logistics network literature primarily focuses on the construction of traditional multistage logistics network models. Traditional multi-stage problems aim to enhance profit for all participant, safe inventory, and maximum customer service levels. Robustly of decision in favor of unclear demand, shipping cost and total delivery time reduction are also in consideration. Traditional logistics networks deal with normal delivery between stages. Direct shipment is the other option where goods move from plant to retailer directly skipping distribution centers. The customer may yet supply the goods from plant or from distribution center directly and not via retailer. This form of delivery demands a different type of logistic network nominated by Gen *et al,* (2008) as Flexible Multistage Logistics Network (fMLN). Figure 1.1 shows this structure.

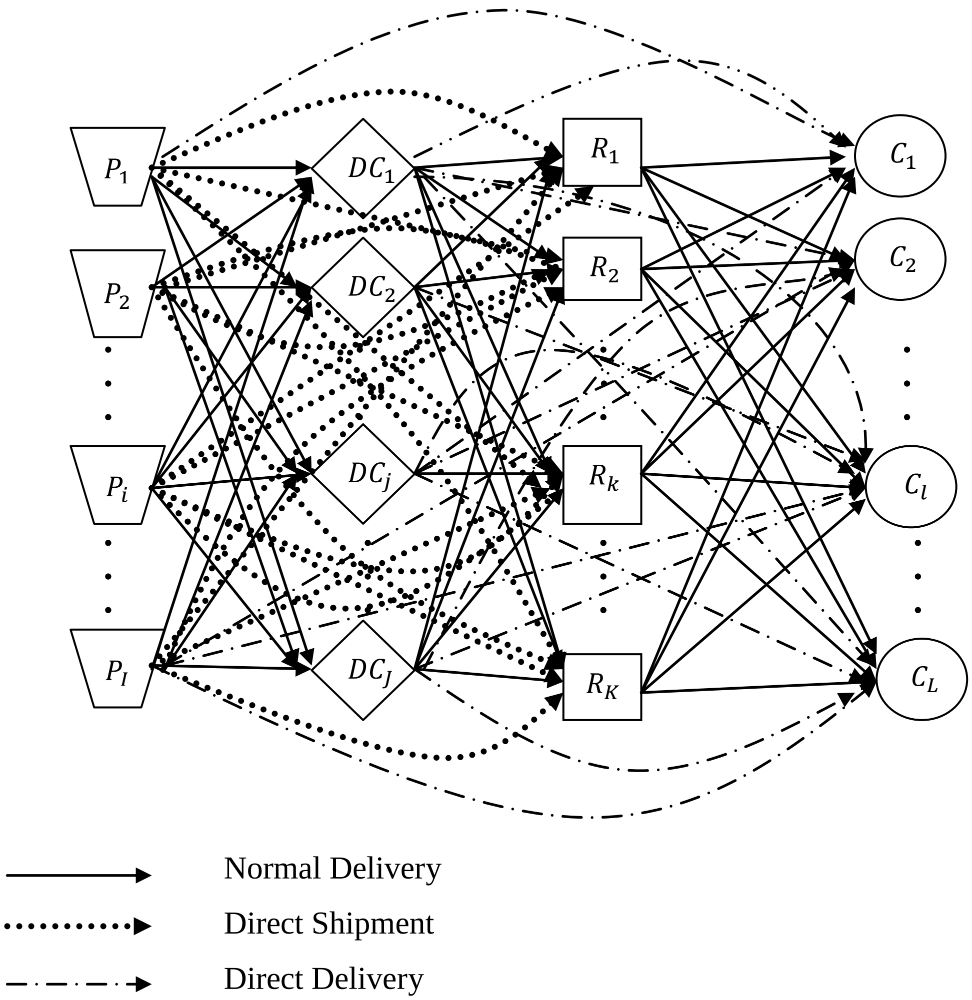

Figure 1.1: The structure of flexible multistage logistics network (fMLN) models (Gen *et al.*, 2008).

Gen *et al*, (2008) also propose the bi-criteria linear logistics model as a unique model for the depiction of the feasible region with a two dimensional criteria space.

This study focuses on the flexible multistage logistics network optimization when network is multi-source at all levels. The structure of the chapter follows with Section 1.2 dealing with the problem background. The problem statement follows under

Section 1.3; and Section 1.4 deals with the research objectives. The scope of the research will be shown in Section 1.5. The brief methodology used in this research will be presented in Section 1.6 and the organization of research can be found in Section 1.7.

1.2 Problem Background

Optimizing a linear function subject to other linear functions over a finite (or countable infinite) set of feasible solutions is known as combinatorial problem. Combinatorial optimization is the rule of decision making in case of discrete alternative (Aarts and Lenstra, 2003). A large number of combinatorial problems are linked with logistic optimization. Many researchers including Gen (2006) pointed out that the optimization problems of logistics network are NP-hard problems.

By tradition, there are many techniques available to solve the optimization problems of logistics network. The usual techniques comprise of linear programming, mixed integer programming and many more. These exact methods can work well, but will cost enormous resources of time and space when solving large-scale problems. Only when the formation of logistics network is simple and there are small number of decision variable and constraint, it can get the exact solution (Chunguang and Songdong, 2007).

Logistic optimization has been acknowledged increasingly as a key issue of supply chain management to improve the business effectiveness under universal competition and diversified customer demands. New delivery modes, identifying between fMLN and traditional counterparts, makes the solution space to the problem much larger and more complex. A large number of decision variables are involved in the general fMLN problem. Solving this problem involves optimization with many constraints and therefore a large problem space. It is, therefore argued that a research on how to develop algorithms with better searching capability focusing on the characteristics of fMLN is required.

For any optimization problem, there is an optimization criterion (i.e. evaluation function) to be minimized or maximized. The evaluation function signifies a measure of the quality of the developed solution. Searching the space of all possible solution is a difficult task. An additional constraint on the domain of search for the parameters makes the problem more complex. The constraints might influence the performance of the evolutionary process since some of the produced solutions (i.e. individuals) may be infeasible. Infeasible solution represents a waste of computation attempt.

Many difficult computational problems from different application areas can be counted as constraint satisfaction problems (CSPs). Constraint satisfaction is vital in computer science. It searches for the optimal solution under a list of constraints. Solutions vary from systematic algorithms to stochastic ones. The complete and systematic methods solve the problem with a significant margin of constraint checks, rendering them applicable only to simple problems. Most of the algorithms are products of the traditional Backtracking Scheme. Incomplete and stochastic algorithms may prove faster; yet they may not necessarily solve the problem albeit under unlimitted time and space (Ionita *et al.*, 2010).

Heuristic usually refers to a method that looks for an optimum solution but does not guarantee it will obtain one, even if one exists. Meta-heuristics are general structures for heuristics in solving hard problems. Earlier to meta-heuristic, a heuristic method has been used in solving combinatorial optimization problems. However, as the problem size becomes larger and complex for real world cases, the method has been very time consuming and decrease in practicality (Masrom *et al.,* 2011).

Meta-heuristics may come under two classes; population-based and point- to-point. The latter only seeks one solution to each iteration repeating the search with the next iteration. The population-based methods on the other hand invoke a number of solutions at the end of each iteration. It may be said that Genetic Algorithm (GA) is an illustration of population-based methods, with Simulated Annealing and Tabu search as examples for point-to-point.

Evolutionary Computation techniques are population-based heuristics, suggested from the natural evolutionary patterns. All techniques in this area work in the same way: they keep a population of individuals (particles, agents) -updated through operators based on fitness information- to achieve better solution areas. The most popular patterns include evolutionary algorithms and swarm intelligence techniques. Evolutionary algorithms are strong search heuristics that operate with a group of chromosomes, as potential solutions. Individuals improve according to the rules of selection and genetic operators. Because operator relevance doesn't warrant offspring feasibility, constraint handling can prove complicated (Ionita *et al.*, 2010).

The GA is most effective in solving complex design optimization problems for its capacity to handle discrete and continuous variables, nonlinear objective and constrain functions without gradient information (Panda and Padhy, 2007). The performance of a genetic algorithm, like any global optimization algorithm, depends on the method for balancing the two conflicting objectives, which are exploiting the best solutions found as far as this and at the same time exploring the search space for talented solutions. The influence of genetic algorithms comes from their capability to mix both exploration and exploitation in an optimal way (Tarek *et al.*, 2006).

Constraint handling is mainly one of the most difficult parts faced in optimization problem. These constraints frequently bound the feasible solution to a small subset. Although genetic algorithms can speedily locate the region in which the global optimum exists, they acquire a comparatively lengthy time to find the exact local optimum in the region of convergence (Tarek *et al.*, 2006). Since fMLN optimization involves a large number of constraints, a simple GA cannot be an efficient technique in terms of obtaining a desired quality solution in a reasonable time. In fact, many researchers have improved the GA implementation to cater for difficult and complex problems.

1.3 Problems Statements

The recent development in fMLN modeling is discussed in Gen *et al.* (2008) which addressed fMLN problem with the assumption of customer order can be fulfilled by only one facility. The fMLN problem in real world logistics and supply chain is more complex. It usually involves multi source where customer order can be fulfilled by multi facilities (plants, DCs and retailers). Furthermore, it also involves customer order for multiple products, and multiple objectives that an operator intends. These may include simultaneous logistic cost and delivery time reduction. fMLN variant modeling and solutions have been ignored by existing researches due to their complexity of decision variables and constraints.

fMLNs with extended decision variables and constraints are questions under combinatorial optimization. Preceding scholarship has used Meta-heuristics methods to solve the problem for its classification as non-deterministic polynomial time hard (NP-hard). Finding optimal solution turns to be exponential to problem size, translating into significant cost/time to the performance of the algorithm. Depending on a single Meta-heuristic method proves restrictive in real life and high complexity problems.

The last decade has seen increasing use of genetic algorithms (GA) for a range of single and multi-objective combinatorial and NP-hard problems (Altiparmak *et al.*, 2006). GA is problem-independent with natural characteristics suitable to optimization problems. The basic attribute is the multiple directional and global searches by maintaining a population of potential solutions from generation to generation. The GA does not have much mathematical requirements concerning the problems and it is able to handle any kind of objective functions and constraints. GA can solve problems regardless of specific internal mechanisms, thanks to its evolutionary nature, making it appropriate to complex problems as opposed to conventional methods (Gen and Cheng, 2000). Yet there are situations in which the simple GA does not perform optimally.

The fMLN problems of this research involve optimizing more than one objective with large number of decision variables and constraints. Therefore by using a simple

GA to solve fMLN problem, finding the feasible region of problem space that all problem constraints are satisfied is not easy as GA is a search based technique and it generates the candidate solutions randomly. Additionally, considering to the nature of GA's operators most probably the infeasible solutions will be generated that some of constraints are violated.

The latest work on GA based solution for fMLN is by Gen *et al.* (2008). The problem addressed here was only for a special case of fMLN. That is a single source, single product and single objective fMLN. In this research the fMLN problem addressed involves the multisource, multi products, and multi objectives cases.

Specifically this research will address the following research questions:

1- How to develop efficient GA based solution techniques for solving multi-source fMLN problems?
2- How to develop efficient GA based solution techniques for solving multi-source multi product fMLN problems?
3- How to formulate the model and develop efficient GA based solution techniques for multi objective multi source fMLN problem?

1.4 Research Objectives

Based on the above mentioned problems statement the objectives of the research are:

1- To develop efficient GA based solution techniques for solving multi-source fMLN problems.
2- To develop efficient GA based solution techniques for solving multi product multi-source fMLN problems.
3- To formulate the model and develop efficient GA based solution techniques for bi-criteria multi source fMLN problem.

The GA based solution algorithm must fulfil the criteria of efficient algorithm namely the ability to obtain near optimum solution within a reasonable computational time.

1.5 Research Scope

Subsequent to the goal and objectives of this study is the research scope. In view of the fact that there is a number of diversity in logistics network model and the existence of Evolutionary Algorithms (EAs) to solve such problems, this study is scoped as follows:

1. In logistics there are some criteria as price and demand estimation, inventory cost, transportation cost, product delivery time and some others, but here we

focus on the two common criteria namely transportation cost and product delivery time.

2. Total shipping cost which is transportation cost with fixed cost of opened facilities will be considered. Other usual cost in logistics network such as inventory cost, warehousing cost, production cost and many more are not the main concerns in this research and will not be considered.
3. Total products delivery time which is the transportation time without consideration to loading/unloading time will be considered. Products delivery time is per shipped which is known in advance.
4. The capacitated logistics network is considered where the capacity of every facility (Plants, DCs and retailers) are constrained and known in advance.
5. Evolutionary Algorithms (EAs), different representing of GA, penalty methods, heuristic rules for problem constraints handling and PARETO solution are considered.

1.6 Methodology of the Research

In general, the methodology of this research is divided into four steps. In the first step, the fMLN mathematical model will be used as a base model and it will be restructured from single source to multi source fMLN model. Subsequently, multi source single product fMLN model will be extended to multi source multi products fMLN model. Furthermore, bi-criteria multi source single product fMLN model will be formulated. In the second step, the standard GA will be used as a base technique to solve the above mentioned problems. It was proved by previous researchers'work that, GA has weaknesses to satisfy a large number of problem constraints and it requires amendments. In the third step of this research methodology, the required amendments of the standard GA to solve variants fMLN models for obtaining an acceptable solution within a reasonable time will be defined. Finally, in forth step, the proposed solutions will be implemented and the obtained solution will be validated.

1.7 Thesis Organization

In general, this thesis comprises of seven chapters. Chapter 1 presents the introduction of the study, problems background, the problems statements, objectives and the scope. Chapter 2 is the literature reviews on multistage logistics network models and their solutions, flexible multistage logistics network model and its solutions, optimization techniques like Evolutionary Algorithms (EAs) and Genetic Algorithms (GAs) which are applied in the logistics problems. Research methodology is discussed in Chapter 3 while Chapter 4 presents the experimental results of GA based solution techniques in solving the multi-source single product flexible multistage logistics network problem. Besides, proposed heuristics rules for GA using penalty function methods to speed up the algorithm and newly proposed representation of GA will be shown in Chapter 4. Extended model of multi source multi product fMLN problem will be considered in Chapter 5 and the proposed algorithms will be developed to solve the mentioned problem. In Chapter 6 the bi-criteria multi source fMLN model will be formulated and solved by developing the proposed algorithm with PARETO solutions. The conclusion and suggestions for future work are explained in Chapter 7.

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