CHAPTER 1

INTRODUCTION

Product distribution is the best known aspect of logistics and supply chain management which includes all services directly linked to the physical movement of goods from plants to customers via warehouses. Moreover, the cost of product distribution accounts for about thirty percent of the cost of the product and it plays a vital role in the determination of a product’s price (Barros et al 2001). Hence, the problem of distribution is an important consideration for industrial firms that have supply chain networks and is the focus of this research. This chapter presents the problem background, proposed solution methodologies, objectives and organisation of the thesis.

1.1 PROBLEM BACKGROUND

The basic structure of a distribution problem is a complex network in which many points such as plants, central depots, warehouses, retailers, and customers are connected by physical or conceptual links such as airways, ships, railways, and roadways. Distribution problems have been dealt in the literature with different dimensions as:

- Single-stage or Multi-stage transportation models,
- Single objective or Multi-objective transportation models,
- Linear or Non-linear transportation cost models, and
- Single-period or Multi-period transportation models.
A single-stage transportation problem basically deals with the problem, which aims to find the best way to fulfill the demand of customers using the supply from plants. The shipment of products from plants is directly shipped to consumers. (i.e. there is no intermediate stage), whereas the multi-stage transportation problem deals with the shipment of the products from plants through the intermediate stages (e.g. supplier, distribution center, retailer and consumer).

Most of the transportation problems involve meeting or achieving a single-objective. The commonly referred to single-objective transportation problem deals with minimising the cost of transportation. The multi-objective transportation problem deals with conflicting objectives like minimising the cost of transportation, minimising delivery time and minimisation of under-used capacity and so on (Li et al 1997).

The classical transportation problem considers only per unit cost of transportation (linear cost) and hence this class of problem can be modelled as linear programming ‘LP’ problem and can be solved to optimality using the Simplex algorithm in polynomial time. The other that has wide acceptance is fixed charge transportation ‘FCT’ problem, where the transportation cost is nonlinear. Two kinds of cost are considered in the fixed charge transportation problems: (i) a continuous cost that linearly increases with the amount transported between a source and a destination, and (ii) a fixed charge, which is incurred whenever a nonzero quantity is transported between a source and a destination. Fixed charge problems arise in a large number of production and transportation systems (Eksioglu et al 2006). Many practical transportation and distribution problems can be modeled as FCT problems (Sun et al 1998; Adlakha and Kowalski 1999; Kim and Pardalos 1999). The FCT problem is an extension of the classical transportation problem in which a fixed cost is
incurred for every supply point that is used in the solution (Schaffer and O’leery 1989).

The strategic decisions in a conventional transportation problem are confined to a single period. Hence, the problem is said to be single-period transportation problem. In practice, the distributions decisions are extended for more than one period (days/weeks/months) to take the advantages of lot sizing. This class of model is referred as multi-period distribution problem ‘MPDP’.

Although distribution research has addressed a variety of models, many practical distribution problems can be modeled as multi-period fixed charge problem. This model has potential in several practical applications such as delivery of automobile accessories from industrial producers to the final automobile assembling centers or the supply of consumer durables to a number of dealers from a number of industrial producers. The transportation cost is the main element in the distribution models. The other considerations of the multi-period distribution models are storage and backorders. At any time period, the total production of the suppliers may or may not be equal to the total demand of the customers. The production shortage (excess demand) occurring at any period can be carried over as backorder to the customer in the forthcoming period. Similarly, the excess production in any period, addressed here as the inventory, is considered as an additional supply available for the forthcoming period. In general, the supplier holds the excess production as inventory. The excess production available at any period can also be stored economically at the customers’ location. The purpose of maintaining inventory at suppliers’ and customers’ locations is to minimize the total distribution cost while integrating transportation, backorder and inventories. The decisions on inventory location and backorder allotment create complexities while integrating transportation, backorder and
inventories. The multi-period fixed charge problem is an extension of the MPDP and FCT problems, where the time based strategic decisions on the size of the shipments, backorders/subcontracts and inventories can make an economical distribution. \textbf{In the light of the above considerations, this thesis considers four multi-period fixed charge models of practical significance for research. They are:}

\begin{description}
\item[Model – 1:] Multi-period fixed charge distribution problem ‘MPFCDP’ associated with backorder and inventories.
\item[Model – 2:] Multi-period fixed charge distribution problem ‘MPFCDP’ associated with subcontract and inventories.
\item[Model – 3:] Multi-period fixed charge production-distribution problem ‘MPFCPDP’ associated with backorder and inventories.
\item[Model – 4:] Multi-period fixed charge production-distribution problem ‘MPFCPDP’ associated with subcontract and inventories.
\end{description}

Table 1.1 distinguishes the four proposed models.

\begin{table}[h]
\centering
\caption{Four different multi-period fixed charge models}
\begin{tabular}{|l|l|l|}
\hline
\textbf{Model} & \textbf{Operational strategy} & \textbf{Production cost} \\
\hline
Model -1 & Backorder with penalty & Same in all suppliers’ location \\
Model -2 & Subcontract & Same in all suppliers’ location \\
Model -3 & Backorder with penalty & Different at all suppliers’ location \\
Model -4 & Subcontract & Different at all suppliers’ location \\
\hline
\end{tabular}
\end{table}
1.2 SOLUTION METHODOLOGIES

A large number of approaches to the modeling and solution for fixed charge problems have been reported in the Operations Research literature (Adlakha and Kowalski 1999; Jawahar and Balaji 2009). These approaches revolve around a series of technological advances that have occurred over that last four decades. These include optimization approaches such as mathematical programming, enumerative techniques, etc. and approximation approaches such as simple problem specific heuristics, artificial intelligence techniques, neighbourhood based search and population based search heuristics. The proposed scheme for classifying scheduling algorithms is shown in Figure 1.1.

The salient remarks concerning these approaches are as follows:

- Optimization algorithms provide satisfactorily or optimal results if the problems to be solved are not too large and are restricted to low-dimensional over-simplified problems. Since, most of the FCT problems have been proved to be Non-deterministic Polynomial-time ‘NP’ hard, i.e., the computational time grows exponentially as a function of the problem size, therefore, optimization algorithms are ruled out in practice. Approximation algorithms are capable of guaranteeing the solution within the fixed percentage of the actual optimum and are considered urgent and useful tools for solving discrete optimization problems.
Figure 1.1 Classification of FCT algorithms

- Mathematical programming has been applied extensively to FCT problems. FCT Problems have been formulated using integer programming and mixed-integer programming. The use of these approaches has been limited because FCT problems belong to the class of NP-hard problems.

- Lagrangian relaxation is a mathematical technique that solves integer-programming problems by omitting specific integer-valued constraints and adding the corresponding costs (due to
these omissions and/or relaxations) to the objective function. Lagrangian relaxation is computationally expensive for large FCT problems.

- Branch-and-bound is an enumerative technique for integer-programming problems. The basic idea of branching is to conceptualize the problem and search for the optimal solution as a decision tree. Although efficient bounding and pruning procedures have been developed to speed up the search, this is still a very computational intensive procedure for solving large FCT problems.

- Simple heuristics have been applied for solving small fixed charge transportation problems. However, this method is more time consuming than the algorithms for solving a regular transportation problem. Besides, this algorithm provides a good foundation for solving small size problems.

- Artificial intelligence techniques include expert systems, knowledge-based systems and neural networks. They can be time consuming to build and verify, as well as difficult to maintain and change. Moreover, since they generate only feasible solutions, it is rarely possible to tell how close that solution is to the optimal solution. Consequently, they have not been used to solve realistic FCT problems.

- The performance of problem specific heuristics is satisfactory as long as the operating characteristics and objectives of the systems remain the same. Heuristics yield good solutions, but are robust to the system.

- Neighbourhood based search heuristics include Tabu Search (TS), Simulated Annealing Algorithm (SAA), and Hill
Climbing Algorithm (HCA). The methodology of SAA has broad appeal in many areas (Balram Suman 2004) and has attractive and unique features when compared with other optimization techniques (Suman and Kumar 2006). Firstly, a solution does not get trapped in a local minimum or maximum by sometimes accepting even the worse move. Secondly, configuration decisions proceed in a logical manner. Moreover, SAA is simple to formulate and it can handle mixed, discrete and continuous problem with ease.


- Population based search heuristics, which belong to the random search strategy, guarantees near optimal solutions in actual cases. The popularly known population based search heuristics are Genetic Algorithm (GA) (Goldberg 2000), Ant Colony Optimization (ACO) (Dorigo et al 1997), Particle Swarm Optimization (PSO) (Kennedy and Eberhart 1995), Bees Algorithm (BA) (Pham et al 2005), Firefly Algorithm (FA) (Yang 2008) and Invasive Weed Optimization Algorithm (IWOA) (Mehrabian and Lucas 2006). These approaches are useful for any hard optimization problem.

Over the last thirty years, there has been a growing interest in problem solving systems based on the principles of evolution.

The above discussion indicates that optimization approaches are limited to smaller size problem instances, and the problem specific simple heuristics, neighbourhood based search meta-heuristics and population based search heuristics are considered as useful tool for fixed charge problems, which are known to be NP-hard (Kim and Pardalos 1999). The multi-period fixed charge problems are much more difficult to solve due to the presence of fixed costs, which cause nonlinearities in the objective function. The complexity of the problem is further increased when time dependent inventories and backorder/subcontract are included in the model. The difficulty of multi-period fixed charge problems can also be understood by the size of the search space. It is determined by standard linear program form.
This means that the maximum number of basic solutions (with M constrains and N variables) to the standard linear program is finite and is given by \((N!/M!(N-M)!))\). This can also be compared with a travelling salesman problem (well known NP hard problem), where the size of the search space is given by \(NC!\) (NC-number of cities). Hence the MPFCDP and MPFCPDP models considered are more complex than the general MPDP and FCT.

In the light of the above, this thesis proposes three heuristics, one each from problem specific heuristics, neighbourhood search based meta-heuristics and population search based meta-heuristics as the tools to evolve optimal or near-optimal solution for the multi-period fixed charge models under study. They are:

- **Problem specific heuristic**: Equivalent variable cost heuristic (EVC)
- **Neighbourhood search based meta-heuristic**: Simulated Annealing Algorithm (SAA)
- **Population search based meta-heuristic**: Genetic Algorithm (GA)

### 1.3 OBJECTIVES OF THE THESIS

The objectives of this research work are:

- Formulation of the mathematical model for all the four multi-period fixed charge models.
- Development of different classes of heuristics for all the four multi-period fixed charge models.
- Evaluation of the proposed heuristics for their performance in terms of solution quality and computational time.
1.4 ORGANISATION OF THE THESIS

In this chapter, the scope of the MPDP and FCT problems, various FCT environments, the advantages and challenges of considering fixed charge in MPDP are discussed. The rest of the thesis is organised as follows:

- Chapter 2 reviews the literature related to multi period distribution models and solution procedures of FCT.
- Chapter 3 describes the characteristics, assumptions and mathematical formulation of the four multi-period fixed charge models considered in this thesis.
- Chapter 4 illustrates the methodology to obtain optimal solution using LINGO for all models, limitation of the LINGO, and model variations.
- Chapter 5 presents the proposed EVC based heuristic and analyses its performance.
- Chapter 6 presents the proposed SAA based meta-heuristic and analyses its performance.
- Chapter 7 presents the proposed GA based meta-heuristic and analyses its performance.
- Chapter 8 discusses the outcome of the research with the results of the various models and algorithms.
- Chapter 9 concludes by presenting the summary of this research and future research directions.