CHAPTER 1

OBJECTIVES AND OUTLINE OF RESEARCH

1.1 INTRODUCTION

In any transportation problem, a basic assumption is that the cost of transportation is directly proportional to the number of units transported (Diaby 1991). Such approaches consider the total cost of transportation as purely quantity dependent and proportional to the amount transported between a source and a destination. However, this assumption cannot be justified in real world situations. For example, rail roads and truck companies invariably use freight rates which consist of a fixed cost, such as permit fee or property taxes, and/or personnel usage. The fixed charge may represent the cost of renting a vehicle, toll charges on a highway, landing fees at an airport, set-up costs for machines in a manufacturing environment, the cost of building roads in transportation systems, time to locate a file in a distributed data base system, etc. 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 fixed charge transportation ‘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). Two kinds of costs are considered in the fixed charge transportation problems: a continuous cost that linearly increases with the amount transported between a source and a destination, and a fixed charge, which is incurred whenever there exist a transportation of a nonzero quantity between a source and a destination. The fixed charge transportation problem continues to be an active area of transportation research (Murty 1968; Gray 1971; Kennington and Unger 1973 and 1976; Robergs and Cooper 1976; Fisk and McKeown 1979; Barr et al 1981; McKeown 1981; Cabot and Erenquc 1984; Palekar et al 1990; Ragsdale and McKeown 1991; Diaby 1991; Herer and Rosenblatt 1996; Lamar and Wallace 1997; Hultberg and Cardoso 1997; Sun et al 1998; Adlakha and Kowalski 1999; Bell et al 1999; Adlakha and Kowalski 2003; Gen et al 2005; Glover 2005; Lawphongpanich 2006; Yang and Liu 2007; Adlakha et al 2007; Jo et al 2007; Klose 2008; Kowalski and Lev 2008). On the above consideration, this thesis considers FCT problems as the broad field of research.

1.2 FIXED CHARGE TRANSPORTATION MODELS

The general FCT problems assume shipment between a source and a destination is fulfilled as a single lot and address single stage environment. However, in Supply Chain ‘SC’ networks, Customers and their needs are the origin. The next stage of the SC is its distribution centres, which in turn, forward the needs of the customers to the manufacturers. In such problems, one of the strategic decisions is the allocation of transaction quantities from production centres to terminal points through distribution agents/centres in a cost effective manner (Chopra and Meindl 2001; Amiri 2006; Gen et al 2006).
The other practical point, which is not addressed in general FCT, is the consideration to the capacity of the transportation media (truck). In real world situations, the lot size may exceed the capacity of the truck and so the shipment has to be done with more than one trip. This leads to increase the fixed charge that is proportional to the number of trips made. Such circumstances, the optimal transportation plan would be different from the one that does not consider the capacity of the truck.

In the light of the above two considerations, this thesis addresses four FCT models of practical significance. They are:

- **Model – 1**: Single-Stage General FCT problem.
- **Model – 2**: Two-Stage Supply Chain ‘SC’ transportation problem associated with a fixed charge.
- **Model – 3**: Single-Stage Truck Load Constrained Fixed Charge Transportation ‘TLC-FCT’ problem.
- **Model – 4**: Two-Stage TLC-FCT problem of a SC.

### 1.3 PROBLEM COMPLEXITY

FCT problems are much more difficult to solve due to the presence of fixed costs, which cause discontinuities in the objective function and are known to be Non-Polynomial ‘NP’ hard (Kim and Pardalos 1999).

The single-Stage FCT problem is involved with a single binary variable that specifies whether the product is transported from the supply point to the demand centres. However, in two-stage supply chain FCT problems, there are two binary variables, one each for each stage.
The inclusion of the truck load constraint in FCT problem converts the binary variable to an integer variable.

Hence all the models considered are more complex than the general FCT and NP-hard.

1.4 SOLUTION METHODOLOGY

A large number of approaches to the modeling and solution for FCT problems have been reported in the OR literature, with varying degrees of success. 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 heuristics, artificial Intelligence (AI) techniques, population based search heuristics and neighbourhood based search heuristics. Figure 1.1 shows the classification of FCT algorithms.
Figure 1.1 Classification of FCT algorithms

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 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.

- 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 (AI) 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 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.

- 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), Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO). 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 and heredity. Such systems maintain a population of potential solutions; they have some selection processes based on the fitness of individuals, and some recombination operators. Genetic Algorithm (GA), which is a random evolutionary search algorithm that mimics the principles of natural genetics. GA, introduced by John Holland in the late sixties, works differently compared to the classical search and optimization methods. Because of their broad applicability, ease of use, and global perspective, among the population based search heuristics, GA has been increasingly applied to various search and optimization problems and has emerged as potential techniques to provide solutions with acceptable accuracy for NP hard problems (Michalewicz 1994; Tate and Smith 1995; Yokota et al 1996; Gen and Cheng 1996;

- Neighbourhood based search heuristics include Tabu search (TS), simulated Annealing Algorithm (SAA), and hill climbing algorithm. They are known for producing excellent results in short run times. Among the neighbourhood based search heuristics, a lot of researchers mostly considered Simulated Annealing Algorithm ‘SAA’ for solving many hard optimisation problems (Kirpatrick et al 1983; Van Laarhoven et al 1987; Oshan and Potts 1989; Eglese 1990; Ogbu and Smith 1990; Dekkers and Aarts 1991; Pirlot 1992; Proth and Souilah 1992; Van Laarhoven et al 1992; Souilah 1995; Zegordi et al 1995; He et al 1996; Pirlot 1996; Shtub et al 1996; Parthasarathy and Rajendran 1997; Ponnambalam et al 1999; Costa and Oliveira 2001; Jayaraman and Ross 2003; Ji et al 2006; Lim et al 2006; Mansouri 2006; Dullaert et al 2007).

The above discussion indicates that population based search heuristics and neighbourhood based search heuristics are useful tool for FCT problems. In the light of the above, this thesis considers GA from the population based search heuristics and SAA from the neighbourhood based search heuristics as the tools to evolve optimal or near-optimal solution for all the four FCT models under study.
1.5 OBJECTIVES OF THE THESIS

The objectives of this research work are:

- Formulation of the mathematical model for all the four FCT models
- Development of GA and SAA based heuristics for all the four FCT models
- Evaluation of the proposed heuristics.

1.6 OUTLINE OF THE THESIS

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

- Chapter 2 addresses literature review.

- Chapter 3 describes the problem formulation, the methodology to find a lower bound and approximate solution and the proposed methodologies (GA and SAA) of the single-stage general FCT problem. The performance comparison of the proposed heuristics for various problem instances is also presented.

- Chapter 4 describes the problem formulation, the methodology to find a lower bound and approximate solution and the proposed methodologies (GA and SAA) of the Two-Stage Supply Chain ‘SC’ transportation problem associated with a fixed charge. The
performance comparison of the proposed heuristics for various problem instances is also presented.

- Chapter 5 describes the problem formulation and the proposed methodologies (GA and SAA) of the Single-Stage Truck Load Constrained Fixed Charge Transportation ‘TLC-FCT’ problem. The performance comparison of the proposed heuristics for various problem instances is also presented.

- Chapter 6 describes the problem formulation and the proposed methodologies (GA and SAA) of the Two-Stage TLC-FCT problem of a SC. The performance comparison of the proposed heuristics for various problem instances is also presented.

- Chapter 7 presents the discussion.

- A summary of the present analysis and an indication of future research directions are presented in the concluding chapter 8.