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Review Article

A LITERATURE REVIEW OF TRANSPORTATION PROBLEMS

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Abstract

Transportation problem nourishes economic and social activity and is cardinal to operations researchand management science. This paper presents a limited survey on various types of transportation problem with its mathematical models.

Keywords: Transportation problem, Bottleneck Transportation Problem, Multi-objective Transportation Problem.

1. Introduction

Transportation problem (TP) is one of the predominant areas of Operations Research and it has wide applications in inventory control, communication network, production planning, scheduling, personal allocation and so forth. Transportation problems play an important role in logistics and supply chain management for reducing cost and improving service.

In today's highly competitive market the pressure on organizations to find better ways to create and deliver products and services to customers becomes stronger. How and when to send the products to the customers in the quantities they want in a cost-effective manner becomes more challenging. Transportation models provide a powerful framework to meet this challenge.

They ensure the efficient movement and timely availability of raw materials and finished goods. The objective of the transportation problem is to determine the shipping schedule that minimizes the total shipping cost while satisfying supply limit and demand requirements.

This paper is organized as follows: Section 2 presents some types of transportation problem such as cost minimizing transportation problem,cost minimizing transportation problem with mixed constraints,Bottleneck transportation problem and multi-objective transportation problem with its mathematical models and the last section presents the conclusions.

2. Various Types of Transportation Problem

2.1 Cost Minimizing Transportation Problem (CMTP)

CMTP popularly known as Hitchock-Koopmann problem in which the objective of the transportation problem is to determine the shipping schedule that minimizes the total shipping cost while satisfying supply and demand limits. Efficient algorithms have been developed for solving transportation problems when the cost coefficients and the demand and supply quantities are known. Hitchcock (1941) gave the mathematical model of the transportation problem. Charnes and Cooper (1954) developed the stepping stone method which provided an alternative way of determining the simplex method information. Dantzig(1963) used the simplex method to the transportation problems as the primal simplex transportation method.Klein (1967) has developed a primal method for minimal cash flows with applications to the assignment and transportation problems. Hadley(1972) also included transportation problem in his book: Linear Programming. Lee (1972) and Ignizio(1976) studied goal programming approach to solve TP. Kwak (1979) used a goal programming model for improved transportation problem. Ahuja (1986) introduced an algorithm for minimax TP. Currin (1986) worked on the TP with inadmissible routes. Sultan (1988) and Sultan and Goyal (1988) studied initial basic feasible solution and resolution of degeneracy in transportation problem. Arsham and Khan (1989) studied a Simplex-type, algorithm for general transportation problem. Kirca and Statir (1990) proposed an algorithm for obtaining an initial solution for the transportation problem.In 1995, Krzysztof Goczyla discussed a routing problem in public transportation network. Adlakha and Kowalski (1999) suggested an alternative solution algorithm for solving certain transportation problem based on the theory of absolute point. Sharma and K.D. Sharma (2000), presented a $O(cn^2)$ heuristic for solving the uncapacitated transportation problem. Sun (2002) worked on the transportation problem with exclusionary side constraints and branch and bound algorithm. Schrijver(2002) worked on the history of transportation and maximum flows. Okunbor(2004) worked on the management decision making for transportation problems through goal programming. Żółkiewski(2008) presented a numerical application for analysis and modelling dynamical flexible systems in transportation. Putcha (2009) developed a method which gives adequate number of entries for starting the transportation simplex algorithm. Adlakha and Kowalski (2009) suggested a systematic analysis for allocating loads to obtain an alternate optimal solution [7]. Immam et al. (2009) used Object-Oriented Model to solve transportation problem.Klibiet al. (2010) discussed the stochastic multi period location transportation problem. Pandian and Natarajan (2010) proposed a new method for finding an optimal solution for transportation problems.

Korukogluand Balli (2011) proposed an improved VAM method for transportation problem. Sharma et al. (2011) used phase-II method of simplex method to solve transportation problem. Solving transportation problem with the help of integer programming problem discussed by Gaurav Sharma et al. (2012). Sudhakar et al. (2012) proposed a new approach for finding an optimal solution for transportation problem. Rekha(2013) discussed optimization techniques for TP of Three Variables. Mollah Mesbahuddin Ahmedet al. (2014) developed an algorithm for finding an initial basic feasible solution for both the balanced and unbalanced TP.In 2014, Rekha et al. proposed a max min penalty approach to cost minimization transportation problem.Sarbjit Singh(2015)proposed resolution of degeneracy in transportation problem.

2.1.1 Mathematical Statement of CMTP

Cost minimizing transportation problem can be stated mathematically as follows:

$$\text{Minimize } z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$$

subject to

$$\sum_{j=1}^{n} x_{ij} = a_i ,\ i = 1, 2, ..., m \ ; \ \sum_{i=1}^{m} x_{ij} = b_j ,\ j = 1, 2, ..., n$$

$x_{ij} \geq 0$, for all i and j

where m is the number of supply points and n is the number of demand points. The production capacity of the ith plant is a_i and the number of units required at the jth destination is b_j.The transportation cost of one unit from the ith plant to the jth destination is c_{ij} and x_{ij} is the number of units shipped from the ith plant to jth destination.

2.2 Cost Minimizing Transportation Problem with Mixed Constraints

In real life, however, most of the costs minimizing transportation problems have mixed constraints accommodating many applications that go beyond transportation related problems to include job scheduling, production inventory, production distribution, allocation problems, and investment analysis. The CMTPs with mixed constraints are addressed very less in the literature because of the rigor required to solve these problems optimally. The more-for-less (MFL) paradox in a transportation problem occurs when it is possible to ship more total goods for less (or equal) total cost, while shipping the same amount or more from each origin and to each destination, keeping all shipping costs non-negative. The primary goal of the more-for-less method is to minimize the total cost and not merely maximize the shipment load transported. The occurrence of more-for-less in TP is not a rare event, and the existing literature has demonstrated the practicality of identifying cases where the paradoxical situation exists (1998). The information of the occurrence of an MFL situation is useful to a manager in deciding which warehouse or plant capacities are to be increased, and which markets should be sought. The MFL paradox in the TP has been covered from a theoretical stand point by Charnes andKlingman (1971), Szwarc (1971), Appa(1973), Isermann(1982) and Charnes et al. (1987). Robb (1990) provided an intuitive explanation of the transportation occurrence. Gupta et al. (1992) and Arsham(1992) obtained the MFL solution for the TP with mixed constraints by relaxing the constraints and by introducing new slack variables. While yielding the best MFL solution, their method is tedious since it introduces more variables and requires solving sets of complex equations. Arora and Ahuja (2000) carried out a research work in paradox on a fixed charge transportation problem. Veena Adlakha and Kowalski (2001) introduced a heuristic method for solving MFL in distribution related problems. Adlakha et al. (2006) proposed a heuristic method for solving transportation problem with mixed constraints. Storoy (2007) studied the revisited transportation paradox. Joshi and Gupta (2010) studied paradox in linear plus fractional transportation problem. Pandian and Natrajan (2010a) have developed fourier method for solving transportation problems with mixed constraints. They converted all the constraints in less than or equal to type constraints and eliminated variables one by one with addition of a specified constraints. Later on, another paper (2010b) presented another method for finding optimal more-for-less solution of transportation problem with mixed constraints. Radindra Nath and Hossain (2012) introduced a modified VAM method for solving TPs with mixed constraints in MFL paradoxical situation. Vishwas Deep Joshi and Nilama Gupta (2012) discussed the identification of more-for-less paradox in the linear fractional transportation problem using objective matrix. Pandian and Anuradha (2013) have introduced path method for finding a MFL optimal solution to a TP. Osuji George et al. (2014) discussed an efficient statistical algorithm for computing paradox in a linear transportation problem if paradox does exist. Kavitha and Anuradha (2015) proposed a new algorithm for finding the cost sensitivity analysis which determines the interval of perturbation to keep the current more-for less (MFL) optimal solution to the transportation problem remaining optimal. Rabindra Nath et al. (2015) introduced a modified VAM method for solving TPs with mixed constraints in MEL paradoxical situation.

2.2.1 Mathematical Statement of CMTP with Mixed Constraints

Cost minimizing transportation problem with mixed constraints can be stated mathematically as follows:

Minimize $z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij}$

subject to

$$\sum_{j=1}^{n} x_{ij} \geq a_i \ , \ i \in \mathrm{Q} \ ; \quad \sum_{j=1}^{n} x_{ij} \leq a_i \ , \ i \in \mathrm{T} \ ; \quad \sum_{j=1}^{n} x_{ij} = a_i \ , \ i \in \mathrm{S} \ ;$$

$$\sum_{i=1}^{m} x_{ij} \geq b_j \ , \ j \in \mathrm{U} \ ; \quad \sum_{i=1}^{m} x_{ij} \leq b_j \ , \ j \in \mathrm{V} \ ; \quad \sum_{i=1}^{m} x_{ij} = b_j \ , \ j \in \mathrm{W} \ ;$$

$x_{ij} \geq 0$ for all i and j and all are integers,

where Q, $T$and S are pairwise disjoint subsets of $\{1,2,\ldots,n\}$ such that $\mathrm{Q} \cup \mathrm{T} \cup \mathrm{S} = \{1,2,...,n\}$; U, Vand W are pairwise disjoint subsets of $\{1,2,\ldots,m\}$ such that $\mathrm{U} \cup \mathrm{V} \cup \mathrm{W} = \{1,2,\ldots,m\}$; c_{ij} is the cost of shipping one unit from supply point i to the demand point j; a_i is the supply at supply point i ; b_j is the demand at demand point j and x_{ij} is the number of units shipped from supply point i to demand point j.

If Q, T, U and V are empty, then the CMTP with mixed constraints becomes the CMTP with equality constraints.

2.3 Bottleneck Transportation Problem (BTP)

The bottleneck transportation problem or time-minimizing transportation problem is a special type of a transportation problem in which a time frame is associated with each shipping route. The objective of this process is to minimize the maximum time to transport all supply to the destinations rather than minimizing the cost. The BTP is encountered in connection with transportation of perishable goods, with the delivery of emergency supplies, fire services or when military units are to be sent from their bases to the fronts. In a BTP, the time of the transporting items from origins to destinations is minimized, satisfying certain conditions in respect of availabilities at sources and requirements at the destinations. Hammer (1969), however, considered the time-minimizing version of this classical problem. Hammer's problem was known as the time TP as well as the bottleneck TP. His problem seeks to minimize the maximum time required to transport goods from sources of supply to different demand destination locations. By considering time minimization, Hammer's work represented a significant departure from the earlier studies of the TP. Subsequently, Garfinkel and Rao (1971), Szwarc (1971), Sharma and Swarup (1977, 1978), Seshan and Tikekar (1980), Khanna, Bakhsi and Arora (1983), Isserman (1984) studied Hammer's problem further, seeking to provide better approaches. Ravi Varadarajan (1991) provided an optimal algorithm for 2 x n bottleneck transportation problems. Sonia and Puri (2004) considered a two level hierarchical balanced time minimizing TP.Ilija Nikolic (2007) demonstrated the total transportation time problem regarding the time of active transportation routes. Peerayuth Charnsethikul and Saeree Svetasreni (2007) introduced an algorithm to solve two classes of the bottleneck transportation problem with an additional budget constraint. Pandian and Natarajan (2011) developed two algorithms, one for finding an optimal solution to bottleneck TP and the other for finding all efficient solutions of a bottleneck- cost TP. Madhuri (2012) presented the solution procedure of linear fractional time minimizing TP with impurities in the commodity to generate total transportation schedules. Sharif Uddin (2012) applied a transportation algorithm to determine the minimum transportation time. Jain and Saksena (2012) discussed the time minimizing TP with fractional bottleneck objective function. Pavel Kolman (2015) proposed a new method to minimize the time of transportation from collection points to places of processing.

2.3.1 Mathematical Statement of BTP

Bottleneck transportation problem can be stated mathematically as follows:

Minimize $z = [\underset{(i,j)}{\text{Maximize}}\ t_{ij} / x_{ij} > 0]$

subject to

$$\sum_{j=1}^{n} x_{ij} = a_i,\ i = 1, 2, ..., m\ ;\ \sum_{i=1}^{m} x_{ij} = b_j,\ j = 1, 2, ..., n$$

$x_{ij} \geq 0$, for all *i* and *j*

where m is the number of supply points; n is the number of demand points; x_{ij} is the number of units shipped from supply point *i* to demand point *j*; t_{ij} is the time of transporting goods from supply point *i* to demand point *j* ; a_i is the supply at supply point *i*and b_j is the demand at demand point *j*.

In a BTP, time matrix $[t_{ij}]$ is given where t_{ij} is the time of transporting goods from the ith origin to the jth destination. For any given feasible solution $X = \{x_{ij} : i = 1,2,\ldots,m$ and $j = 1,2,\ldots,n\}$ of the problem (P), the time transportation is the maximum of t_{ij}'s among the cells in which there are positive allocations. This time of the transportation remains independent of the amount of commodity sent so long as $x_{ij} > 0$.

2.4 Multi-objective Transportation Problem (MOTP)

In the cost minimizing transportation problem of linear programming, the traditional objective is one ofminimizing the total cost. In general, the real life problems are modelled with multi-objectives which aremeasured in different scales and at the same time in conflict. In many practical situations multiple penalty criteria may exist concurrently, which forced researchers to think and work for multi-objective transportation problem. A variety of approaches, such as lexicographic goal programming approach, interval goal programming approach, interactive algorithms, fuzzy programming approach, the step method, the utility function method have been developed by many researchers for the multi-objective linear programming problem.

Lee and Moore (1973) applied goal programming approach to find a solution of multi-objective transportation problem. Iserman (1979) presented an algorithm for solving linear multi- objective transportation problems by which the set of all efficient solutions was enumerated. Leberling (1981) used hyperbolic membership function for multi-objective linear programming problem. Ringuest and Rinks (1987) proposed interactive algorithms to find more than k non-dominated and dominated solutions if there are k objectives. Thus the decision maker has to determine a compromise solution from the set of non-dominated solutions. Bit et al., (1992) have shown the application of fuzzy programming to multicriteria decision making classical TP. Bit and Alam (1993) proposed an additive fuzzy programming model for the multi-objective transportation problem. Verma et al. (1997) discussed a special type of non-linear membership functions to solve the multi-objective TP. Hussien (1998) studied the complete set of α -possibly efficient solutions of multi-objective TP with possibilistic coefficients of the objective functions. Mistuo et al. [1999] presented a spanning tree-based genetic approach for solving a multi objective transportation problem. Das et al. (1999) used fuzzy programming approach for solving multi-objective interval transportation problem. Li and Lai (2000) studied a fuzzy compromise programming approach to multi-objective TP. Waiel F. and El-Wahed (2001) studied multi-objective transportation problem under fuzziness. Ali et al.(2011a, 2011b) have also used the integer nonlinear goal programming approach in multi-objective reliability optimization and sample surveys problem. Ammar and Youness (2005) discussed the efficient solutions and stability of MOTP with fuzzy coefficient and/or fuzzy supply quantities and/or fuzzy demands quantities. Wahed and Lee (2006) gave an interactive fuzzy goal programming approach to determine the preferred compromise solution for the MOTP. The approach focuses on minimizing the worst upper bound to obtain an efficient solution which is close to the best lower bound of each objective function. Zangiabadi and Maleki (2007) proposed a fuzzy goal programming approach to determine an optimal compromise solution for the MOTP by assuming that each objective function has a fuzzy goal. The method focuses on minimizing the negative deviation variables from 1 to obtain a compromise solution of the MOTP. Surapati and Roy (2008) studied a priority based fuzzy goal programming approach for solving a MOTP with fuzzy coefficients. Lau et al. (2009) gave an algorithm called the fuzzy logic guided non-dominated sorting genetic algorithm to solve the MOTP that deals with the optimization of the vehicle routing in which multiple products, multiple customers and multiple depots are considered. Lohgaonkar and Bajaj (2010) used the fuzzy programming technique with linear and non-linear membership function to find the optimal compromise solution of a multi-objective capacitated TP.Sayed et al. (2012) used genetic algorithm for solving multi objective transportation problem, assignment, and trans shipment problems. Osuji et al. (2014) used the fuzzy programming algorithm to find the solution of multi-objective transportation problem. Abbas et al. (2015), presented a non-dominated point for the multi-objective transportation problem.

2.4.1 Mathematical Statement of MOTP

Multi-objective transportation problem can be stated mathematically as follows:

$$\text{Minimize } F^k(x) = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij}^k x_{ij}$$

subject to

$$\sum_{j=1}^{n} x_{ij} = a_i,\ i = 1,2,\ldots,m\ ;\ \sum_{i=1}^{m} x_{ij} = b_j,\ j = 1,2,\ldots,n$$

$x_{ij} \geq 0$, for all i and j

Where a_i is the amount of the material available at ith source; b_j is the amount of the material required at jth destination; $F^k(x) = \{F^1(x), F^2(x), \ldots, F^k(x)\}$ is a vector of K objective functions and the superscript on both $F^k(x)$ and c_{ij}^k are used to indicate the number of objective functions $k=1,2,\ldots,K$.

3. Conclusion

This paper provides the limited survey on some types of transportation problem such as cost minimizing transportation problem, cost minimizing transportation problem with mixed constraints, bottleneck transportation problem and multi-objective transportation problem with its mathematical models.

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