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# A heuristic solution technique to attain the minimal total cost bounds of transporting a homogeneous product with varying demands and supplies

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ABSTRACT

Transportation of a product from multi-source to multi-destination with minimal total transportation cost plays an important role in logistics and supply chain management. Researchers have given considerable attention in minimizing this cost with fixed supply and demand quantities. However, these quantities may vary within a certain range in a period due to the variation of the global economy. So, the concerned parties might be more interested in finding the lower and the upper bounds of the minimal total costs with varying supplies and demands within their respective ranges for proper decision making. This type of transportation problem has received attention of only one researcher, who formulated the problem and solved it by LINGO. We demonstrate that this method fails to obtain the correct upper bound solution always. Then we extend this model to include the inventory costs during transportation and at destinations, as they are interrelated factors. The number of choices of supplies and demands within their respective ranges increases enormously as the number of suppliers and buyers increases. In such a situation, although the lower bound solution can be obtained methodologically, determination of the upper bound solution becomes an NP hard problem. Here we carry out theoretical analyses on developing the lower and the upper bound heuristic solution techniques to the extended model. A comparative study on solutions of small size numerical problems shows promising performance of the current upper bound technique. Another comparative study on results of numerical problems demonstrates the effect of inclusion of the inventory costs.


## 1. Introduction

In today's competitive business environment, integrated suppliers–buyers supply chain management is a major concern. Two of the key issues in this supply chain management are the transportation and the inventory costs. To achieve significant savings, these two issues should be integrated instead of treating them separately. The transportation problem deals with transporting a homogeneous product from multi-source to multi-destination, with the minimal total cost of transportation subject to the satisfaction of the available supply and the demand quantities. However, each of the supply and demand quantities of a product may vary within a certain range in a period due to the variation of the global economy. Following this variation, the minimal total transportation cost also varies within a certain range. So, the concerned parties might be more interested in finding the lower and the upper bounds of the minimal total costs for better decision making specifically, for proper investment and return. But the number of choices of supply and demand quantities within their respective ranges increases enormously as the number of suppliers or buyers increases. However, this type of transportation problem can be reduced to a linear programming problem following Liu (2003)'s approach, and then it can be further reduced to the minimum cost flow problem (Ahuja, Magnanti, & Orlin, 1993). Thereafter, a polynomial time algorithm can be applied to this minimum cost flow problem for finding the lower bound of the minimal total costs. Thus, in such a situation, although the lower bound of the transportation problem can be found methodologically, determination of the upper bound of the minimal total costs becomes an NP hard problem. Inventory costs during transportation and in meeting demand from destinations are essential in this system, and hence these should be considered along with the transportation cost. The format of the extended transportation model including these inventory costs is equivalent to the original one of Liu (2003) (as shown later in Section 2.4). In this situation, development of a heuristic solution method to the extended transportation model in finding the upper bound of the minimal total costs is desirable. Although a solution method to the problem without taking into

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account the mentioned inventories is available, here we demonstrate that this does not lead to the correct upper bound solution always. Therefore, this study mainly considers an integration of the transportation and the inventory costs in transporting a homogeneous product from multiple suppliers to multiple buyers, and development of a better heuristic solution technique to this integrated supply chain problem in finding the upper bound of the minimal total costs.

Hitchcock (1941) formulated the transportation problem initially. Then Charnes and Copper (1954) developed the stepping stone method for solution of the transportation problem. Srinivasan and Thompson (1977) described two new primal basic methods – the cell and area cost operator algorithms for solving the transportation problem. Søren (1978) explained how to use the triple index and the threaded index for storing the basis-tree when applying the primal, dual or primal–dual simplex method to solve a classical transportation model. Donald and Haluk (1997) showed that general transportation algorithms automatically yield solution in integer values with integer demand and supply quantities. Sharma and Sharma (2000) proposed a new solution procedure to solve the incapacitated transportation problem. Sharma and Prasad (2003) presented a heuristic that obtained a very good initial basic feasible solution to the transportation problem in O ($n^3$) time. Veena Adlakha and Kowalski (2009) proposed an alternative algorithm to obtain the minimal total cost solution. Saleem and Imad (2012) developed a hybrid two-stage algorithm (GA-RSM) to find the minimal total cost solution to the transportation problem. The first stage used genetic algorithm (GA) to find an improved initial basic feasible solution, and the second stage utilized this solution as a starting point in the revised simplex method (RSM) to get the minimal total cost solution to the problem. Aizemberg, Kramer, Pessoa, and Uchoa (2014) studied tactical models of scheduling the shipments of a crude oil through routes linking platforms (offshore production sites) and terminals (onshore consumer sites) with the minimum transportation cost. Vancroonenburg, Croce, Goossens, and Spieksma (2014) studied the Red–Blue Transportation Problem (Red–Blue TP), a generalization of the transportation problem where supply nodes are partitioned into two sets. Here, they provided two integer-programming formulations for Red–Blue TP and showed that one of them is strictly stronger than the other. They also presented a maximization variant of Red–Blue TP (by modifying the objective function of the Red–Blue TP to maximization) and thus provided three approximation algorithms for Max–Red–Blue TP. All of these solution procedures to the transportation problem were developed with fixed supply and demand quantities. But a little attention has also been given in developing transportation models with variable parameter values. Das, Goswami, and Alam (1999) proposed a solution for solving the multi-objective transportation problem, where the coefficients of terms in the objective functions and parameter values at the sources and the destinations were given in an interval. Safi and Razmjoo (2013) focused on the transportation problem where a fixed charge was added with the transportation cost per unit, and parameters values were given in intervals. They proposed two solution procedures to this problem. Note that both Das et al. (1999) and Safi and Razmjoo (2013) did not make any attempt to find the lower and the upper bounds of the minimal total cost following the parameter values in intervals. Liu (2003) investigated the transportation problem when the demand and supply quantities were varying within their respective ranges. Following these variations the minimal total cost were also varied within an interval. So, he constructed a pair of mathematical programs where at least one of the supply or the demand was varying, to calculate the lower and the upper bounds of the total transportation cost.

A considerable amount of research dealing with the management of the integrated supplier–buyer system involving joint inventory and transportation cost has emerged in the literature. Ben-Daya and Hariga (2004), Hill (1999), Hill and Omar (2006), Hoque and Goyal (2000), Kaya, Kubalı, and Örmeci (2013), Stanisław (2003), and Zhou and Wang (2007) all have considered inventory and transportation cost in the single-vendor single-buyer integrated inventory system. Banerjee and Burton (1994), Burns, Hall, Blumenfeld, and Daganzo (1985), Chan and Kingsman (2007), Darwish and Odah (2010), Hoque (2008, 2011a, 2011b), Kang and Kim (2010), Lu (1995), Shen, Coullard, and Daskin (2003), Yang and Wee (2002), and Zavanella and Zanoni (2009) have taken into account inventory and transportation costs in the integrated single-vendor multi-buyer system. Ben-khedher and Yano (1994) studied the problem of scheduling the delivery of multiple items from a single supplier to a manufacturer. Then, they proposed a heuristic solution approach to minimize the sum of the transportation and the inventory costs. Cetinkaya and Lee (2000) presented an analytical model for coordinating the inventory and the transportation decision in a vendor-managed inventory system. Chan, Muriel, Shen, Levi, and Teo (2002) proposed a model to design simple inventory policies and transportation strategies to satisfy time-varying demands over a finite time horizon, while minimizing the system wide cost by taking advantage of quantity discounts in the transportation cost structure. Shu, Teo, and Shen (2005) studied stochastic transportation–inventory network design problem involving one supplier and multiple retailers. Berman and Wang (2006) considered the problem of selecting the appropriate distribution strategy for delivering a family of products from a set of suppliers to a set of plants so that the total transportation and inventory costs are minimized. Ertogral, Darwish, and Ben-Daya (2007) incorporated the transportation cost explicitly into a model and developed optimal solution procedures for solving the integrated model. Kutanoglu and Lohiya (2008) presented an optimization-based model to gain insights into the integrated inventory and transportation problem for a single-echelon, multi-facility service parts logistics system with time-based service level constraints. Christoph (2011) focused on a single buyer sourcing a single product from a pool of heterogeneous suppliers. The author tackled the supplier selection and lot size decision with the objective of minimizing the total system cost of inventory, transportation, setup and ordering. Janeiro, Jurado, Meca, and Mosquera (2013) proposed a new cost allocation rule for inventory transportation systems. Glock and Kim (2014) studied shipment consolidation in multiple vendors and a single buyer integrated inventory model. In developing the model, the buyer was assumed to consolidate deliveries by assigning vendors to groups to reduce transportation and handling costs.

Researchers have given considerable attention to the single-supplier single-buyer, single-supplier–multi-buyer and multi-supplier–single-buyer systems involving the joint inventory and transportation cost. Although the multi-source multi-destination system has received some attention, only Liu (2003) developed a method to find both the lower and the upper bounds of the minimal total costs of transporting a homogeneous product in this system with variable supply and demand quantities. However, we demonstrate here that Liu (2003)'s method is unable to provide the exact upper minimal total cost bound solution. Therefore, we intend to develop a better heuristic solution technique to find the upper minimal total cost bound to the problem along with a heuristic solution technique to obtain the lower minimal cost bound. In developing the heuristics, we have proved theoretically that it is possible to obtain the best upper minimal total cost bound by reduction in any pair of supplier–buyer's supply–demand quantities by the same integral amount. Analogously, in case of finding the lower minimal total cost