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A supply chain network design considering transportation cost discounts

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ABSTRACT

This study addresses an integrated facility location and inventory allocation problem considering transportation cost discounts. Specifically, this article considers two types of transportation discounts simultaneously: quantity discounts for inbound transportation cost and distance discounts for outbound transportation cost. This study uses an approximation procedure to simplify DC distance calculation details, and develops an algorithm to solve the aforementioned supply chain management (SCM) problems using nonlinear optimization techniques. Numerical studies illustrate the solution procedures and the effects of the model parameters on the SCM decisions and total costs. Results of this study serve as a reference for business managers and administrators.

1. Introduction

The value of inventory is approximately 14% of gross domestic product (GDP) in the United States, while annual transportation and warehousing expenses average approximately nine percent of GDP (Wilson, 2005). Retail companies in the US spend approximately $14 billion per year on inventory interest, insurance, taxes, depreciation, obsolescence, and warehousing. Their logistics activities account for 15–20% of the total cost of finished goods (Menlo, 2007). With such a huge logistics investment, it is important to make sound decisions for facility locations and inventory allocation in a supply chain (SC). The design and management of SC network in today's competitive business environment is one of the most important and difficult problems that managers face.

In today's business environment most retail companies have complex distribution networks with several national and regional distribution centers (DCs). For example, Target, Inc. has three import warehouses, 22 regional distribution centers, and 1300 retail stores. Frito-Lay, Inc. operates its distribution network with 42 plants, one national DC, and 325 regional DCs (Erlebacher and Meller, 2000). When goods arrive at US seaports, they must be consolidated by regions at national (import) DCs. From these national distribution centers (NDCs), goods are shipped to regional distribution centers (RDCs), from which they are delivered to retail stores. There exists a substantial cost in transportation goods from NDCs to RDCs and from RDCs to retailers. In practice, discount for larger quantity of freight or longer distance of shipment may be applicable to transportation economies of scale (Shinn et al., 1996). Since logistics cost plays a key factor in SC design and management decisions, incorporating transportation cost discounts into SC network design problem is necessary. The current paper is the first SC network design study to consider transportation cost discounts.

Since the SC network is a large-scale complex system, detailed modeling and optimization are difficult (e.g., see several examples of detailed discrete modeling in Section 2). Since our focus in this study is the strategic decision making, this article

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presents a two-phase approximation technique to solve the SC network design problem. This approximation leads to a substantial reduction in the amount of data characterizing the SC system. The resulted simplified system is then much easier for optimization and comparison studies to explore managerial insights. Specifically, the proposed solution formulates transportation traveling distance and cost with continuous functions of the sizes of influential area covered by DCs. Since the SC network design involves multiple parameters and the objective function could be nonlinear with bounded constraints, this study provides heuristic algorithms to solve this optimization problem. The following provide details to further support the approximation approach.

While discrete models (see examples in Section 2) can provide managers with optimal solutions, their data and computational requirements increase tremendously as they become more realistic. Moreover, data reliability and model accuracy are of concerns in practice, especially in dynamically changing business environment. The key idea of the continuous approximation (CA) approach is to define decision variables using continuous functions for reducing SCM problem complexity. Although the CA approach does not determine the exact location of the distribution centers, it defines a service area for each distribution center in terms of circular influence areas. Studies by Newell (1973) (and Dasci and Verter, 2001) showed that influence area with central distribution nodes is a near optimal solution. See Section 2 for more examples of CA approaches in solving SCM problems.

The goal of this study is to provide logistics network planners with a high-level solution for the integrated facility location and inventory allocation problem under quantity and distance discounts for transportation costs. Chen (2010) and Chen and Chang (2010) emphasized the importance of integrated decision-making. Specifically, this study intends to determine the following SC network design decisions: (1) which RDC locations should be open, (2) which retail store should be served from which RDC, and (3) how much inventory should be held at the NDCs and the RDCs? We consider both situations when order quantity is the same across all RDCs and when order quantity is different at RDCs in different regions. Two heuristic algorithms are provided to solve the problems. Numerical study illustrates the solution procedures and impacts of the relevant model parameters on SC design decisions and profits.

The remainder of this study is organized as follows. Section 2 reviews key literature relevant to the studies. Section 3 describes the problem including assumptions and notations. Section 4 formulates the model and develops a heuristic algorithm for solving the problem. Section 5 presents numerical examples and analyses to illustrate the solution procedure and impact of changing system parameters. Section 6 extends the procedure to solve more realistic problems. Finally, Section 7 concludes the study.

2. Literature review

2.1. Supply chain network design

In recent years, many retail companies have explored better ways for designing and managing their SC for achieving cost savings. There are several publications in the area of integrated facility location and inventory decisions. Shen (2007) has made a complete review of the supply chain design literature and of current practices. Daskin's (1995) fixed-charge facility location model uses the linear inventory cost function to determine DC locations achieving the least cost. Nozick and Turnquist (1998) approximated the safety stock cost at each DC using a linear regression function of the number of DCs. They then used this function to estimate the inventory cost function. Their model stocks inventory at the DC and replenishes it using a one-for-one policy. Nozick and Turnquist (2001) extended their previous model by adding service responsiveness and uncertainty to DC delivery time. They defined service responsiveness in terms of stock-outs and time-based delivery. Stock-outs are incorporated in the safety stock function while the time-based delivery constraint is modeled explicitly as coverage distance.

Daskin et al. (2002) and Shen et al. (2003) proposed a set-covering model to consider location and allocation policies for a DC-retailer network with risk pooling. They successfully showed that this problem can be solved efficiently when the DC demand is deterministic or Poisson distributed. Shu et al. (2005) extended this model to consider arbitrary demand distributions. They presented computational results for several instances, with sizes ranging from 40 to 500 retailers. Shen (2005) considered a location-allocation problem for a multi-commodity supply chain. Shen and Daskin (2007) extended the nonlinear integrated location-inventory model to incorporate a measure of customer service quality. Shen and Qi (2007) removed the assumption in Shen et al. (2003). They modeled the shipment from a DC to its customers using a vehicle routing model instead of the linear direct shipping model, and proposed a Lagrangian relaxation based solution algorithm. Javid and Azad (2010) established a heuristic method based on a hybridization of Tabu Search and Simulated Annealing to solve the location, routing and inventory problem.

For location-allocation and inventory policies, Teo and Shu (2004) proposed a set-covering model to design a two-echelon warehouse-retailer network under deterministic retailers demands. Their problem was to determine the optimal warehouses locations, allocate retailers to warehouses, and make inventory decisions for warehouses and retailers. Their objective was to minimize the total two-echelon inventory, transportation, and facility location cost. They provided computational results for problems involving 20 warehouses and 100 retailers. Romeijn et al. (2007) extended the problem to consider an additional cost term that may represent costs related to safety stocks or capacity considerations. They studied the structure of the pricing subproblem and developed an algorithm to solve it, providing computational results for problems