Ain Shams University
Faculty of Engineering

Supply Chain Network Design

A Thesis
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M.Sc. Mechanical Design and Production Engineering

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Statement

This thesis is submitted in the partial fulfilment of doctorate degree in Mechanical Engineering to Ain Shams University.

The author carried out the work included in this thesis, and no part of this thesis has been submitted for a degree or qualification at any other university.

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Supply Chain Network Design

Abstract

Supply chain management has recently gained a lot of interest. In their studies, researchers try to put assumptions that are close to real supply chain networks. In this research, the problem addressed is a supply chain network of three echelons, multiple products, of stochastic demand, with inventory accumulation over multiple planning intervals. A mathematical model was built to find the optimum decision of operating facilities and distributors. The problem is formulated in stochastic integer linear programming. The objective is to maximize the expected profit. The model was proven to be effective solving this problem. Such a problem was not tackled by many researchers due to its complexity, and big size. Further studies were made to decrease the size of the problem. It was made possible to decrease the computational time to about 40% of the original time while obtaining the same results. This percentage depends on the original size of the problem.

Experiments were carried out to study the effect of different parameters of the problem on the profit and the service level. Parameters studied were the fixed and variable costs, as well as the variance of the stochastic demand. The model was extended to feature bidirectional transshipment among distributors. Allowing transshipment between distributors has proven to be effective and profitable in some cases, depending on the three main parameters; the transshipment cost, the holding cost, and the transportation cost between facilities and distributors. Finally, the bullwhip effect at facilities was calculated for different cases of transshipment and inventory. Inventory and transshipment help to decrease the bullwhip effect at facilities under different scenarios through the same planning interval. On the other hand, they help to increase the variation in the production rate through different intervals.

Keywords: Supply chain, stochastic demand, location allocation, integer linear programming, multi-periods, multi-product, bidirectional transshipment

Summary of the Ph.D. Thesis
"Supply Chain Network Design"

Supply Chain has recently raised a lot of interest in the research due to its effect on the profitability for all the supply chain network members. Researchers studied supply chains from different aspects. Some researchers were interested in strategic decisions, and supply chain design. Other researchers proposed methods to improve the performance of the network. Others were interested in just measuring the performance of the network under different conditions.

Many researchers studied supply chains under deterministic conditions. For the remaining who studied the supply chains under stochastic conditions, most of the research was held for a single product, or a single echelon, or a single planning interval. Limited research studied multi-echelon, multi-interval, multi-product stochastic supply chains. The most used method to design the supply chain was mathematical programming, like integer, and mixed integer linear programming, stochastic programming, and non-linear programming. Besides, some researchers modeled supply chains using different types of Petri Nets; like ordinary Petri Nets, stochastic Petri Nets, color Petri Nets, and complex-valued token Petri Nets. The literature on supply chain optimization has traditionally considered the decisions of operating facilities and distributors as strategic decisions in the supply chain design. On the other hand, it considered the flow of material from one stage to another as planning decisions.

In this thesis, strategic and planning decisions are integrated in designing supply chain networks. The problem addressed is a supply chain network of multi-echelon, multi-product, of stochastic demand, with inventory accumulation over multiple planning intervals. The network consists of three echelons; the facilities, the distributors, and the customers, allowing for inventory at distributors -if needed. A mathematical model was built to find out the optimum decisions of

operating facilities and distributors. The problem is formulated in stochastic integer linear programming. The objective is to maximize the expected profit. The same model was modified to allow inventory at facilities instead of distributors, while maximizing the expected profit. The model was further extended to feature bidirectional lateral transshipment among the distributors.

The proposed model was tested using some sets of problems that include different supply chain cost parameters. The parameters were the fixed costs of locations, the transportation costs, the production costs, the holding costs, and the shortage costs. Parameters governing the transshipment process were also tested. These parameters are the transshipment cost, the holding cost, and the transportation cost between facilities and distributors. The bullwhip effect due to transshipment was measured. Different supply chain structures were considered to facilitate the discussion of the results and easily interpret them.

Solving these problems showed the complexity of the design problem of supply chains of multi-echelon, multi- product under stochastic demand over multiple intervals. Due to the fact that the size of the problem is huge, it was required to simplify the problem. For example, a network of three facilities and three distributors dealing with three deterministic products over two planning intervals can be represented by integer linear programming of 189 variables subject to 135 constraints. In case of stochastic demand of only three discrete sections, the problem involves 35,721 scenarios. A heuristic based on pre-experimentations was built to reduce the number of scenarios.

The results obtained from solving these problems by the proposed model showed that the model is capable of solving the assigned problem. Results proved that by using the proposed heuristic, computational time can be shortened (down to about 40% of the original time), without losing the accuracy of the solution. The results have proven to be near-optimal. The shortened computational time was found to depend on the original size and parameters of the problem.

Results also proved that there are inverse relations between the variable costs of the product as well as the fixed costs of locations, and the profit. Fixed costs of locations have no effect on the service level. All variable costs have inverse relations with the service level, except for the shortage cost which has a direct proportionality relation with the service level.

It was proven that transshipment between distributors can improve the performance of the supply chain, and be more profitable than direct transportation from the facilities to the distributors. As the transportation cost between facilities and distributors increases, the quantities transshipped increase. On the other hand, as the transshipment and the holding costs decrease, the quantities transshipped increase.

The bullwhip effect was measured for three cases of transshipment and inventory; with transshipment, without transshipment with inventory, and without transshipment without inventory. It was found that both inventory and transshipment help to decrease the bullwhip effect at facilities under different scenarios within the same planning interval. They also increase the variation in the production rate at facilities from one interval to another.

It was proven that supply chains operating under demands higher than their capacities face lower bullwhip effect than those operating under demands less than their capacities.

Table of Contents

Subject			*Page*

List of Tables

List of Figures