MODELING THE INVENTORY COORDINATION DECISIONS IN A MULTI-STAGE SUPPLY CHAIN

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MODELING THE INVENTORY COORDINATION DECISIONS IN A MULTI-STAGE SUPPLY CHAIN

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To my beloved mother and father
To my wife, and children.
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In the past, supply chain production-inventory decisions were not well-coordinated and information was not shared among the different relevant parties. However, recently, supply chain production and inventory coordination have been getting a lot of attention and because of that, numerous models on how to minimize the supply chain total cost and improve customer service have been developed. Currently, most of these developed models deal with two-stage chains. Although multi-stage supply chains were also considered, most of these developed models were based on certain restrictive assumptions. Therefore, there is a need to analyze models that are not restricted by the usual assumptions as this would allow for a more realistic analysis of the supply chain. The objective of this research is to identify the role of the supply chain decisions in the coordination and optimization of costs and accepted service levels. This was done by formulating mathematical optimization integrated models for the case of multi-stage non-serial supply chains. These models took into account three different inventory coordination mechanisms which were the equal cycle, the integer multipliers and powers of two multipliers. Then, the cost minimization procedures were applied in order to obtain feasible and satisfactory solutions to the problem. Numerical analysis indicated that the use of the integer multipliers coordination mechanism resulted in the lowest total costs. To entice this coordination, a benefit sharing scheme was proposed. In conclusion, the multi-stage supply chain cost efficiency can be improved drastically via centralized inventory coordination, mutual trust and proper coordination using a benefit sharing scheme.
ABSTRAK

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

In the past, supply chain production-inventory decisions were not coordinated among the different parties in the supply chain. This lack of coordination leads to weakly connected processes and isolated decisions across the supply chain. Recently firms realized the need to improve their system performance and cost efficiency through closer collaboration among the chain partners and through high level of coordination of various decisions. This tendency towards full integration and close collaboration is also motivated by the significant advances in information and communication technologies, and the growing focus on supply chain management (SCM).

The term Supply chain management seems to have emerged in the late 1980s and since then many definitions of SCM have been proposed (Nahmias, 2001). In this introduction, we will present few of them. According to Stanford Supply chain forum, Supply chain management deals with the management of materials, information and financial flows in a network consisting of suppliers, manufacturers, distributors, and customers. Somichi-Levi et al.(2003) defines supply chain management as a set of approaches utilized to efficiently integrate suppliers, manufactures, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide cost while satisfying service level requirements.
Ross (1998) defines supply chain management as a continuously evolving management philosophy that seeks to unify the collective productive competencies and resources of the business functions found both within the enterprise and outside the firm’s allied business partners located along intersecting supply channels into a highly competitive, customer-enriching supply system focused on developing innovative solution and synchronizing the flow of marketplace products, services, and information to create unique individualized sources of customers, Nahmias (2001). Ellram (1991) defines Supply chain management as a coordinated approach for managing the flow of goods from suppliers to ultimate consumers.

Supply chain management is mainly aimed at enhancing the competitive performance of the entire supply chain via efficient integration of the different chain members. This integration includes functional integration, spatial integration, and intertemporal integration. Functional integration refers to integration of purchasing, manufacturing, transportation, warehousing and inventory management activities. Spatial integration refers to integration of these activities across geographically dispersed vendors, facilities and markets. Intertemporal integration refers to the integration of these activities over strategic, tactical, and operational planning horizons (Shapiro, 2001).

In summary, Supply Chain Management (SCM) can be defined as the management of flows of goods between the different stages in a supply chain in order to minimize system-wide cost and satisfy customer requirements.

![Four-stage supply chain network](image)

**Figure 1.1: Four-stage supply chain network.**
The supply chain is often represented as a network like the one displayed in Figure 1.1. The nodes in the network represents the facilities, which are connected by the transportation links that allow the flow of materials, the flow of information and the flow of cash across the chain. Figure 1.1 depicts a supply chain that has four stages, which are vendors, plants distributors and retailers.

### 1.2 Supply chain modeling

There are variety of supply chain models developed for varying supply chain management and planning objectives. Shapiro (2001) classified mathematical models developed for implementation and application in supply chain management into two main types: descriptive models and optimization models.

Descriptive models are created by modeling practitioners to better understand functional relationship in the supply chain. They include demand forecasting models, cost relationship model, resource utilization relationship models, and supply chain system simulation model. Optimization models are either prescriptive models or normative models. Prescriptive models support the decision making process in identifying a set of decisions that can enhance the supply chain performance. Normative models help in identifying norms that the company should strive (Shapiro, 2001).

### 1.3 Production-Inventory coordination in the supply chain

Supply chain production-inventory distribution coordination is a centralized planning process that deals with production lot-sizing, production scheduling, shipment quantities, and inventory allocation. In the centralized production and replenishment decision policy, the global supply chain costs are optimized. While in the decentralized production and replenishment decision policy, each participant within the supply chain will consider optimizing its own costs independently.
In recent years numerous articles in supply chain modeling have addressed the issue of inventory-distribution coordination. Several researchers focused on the integrated vendor-buyer inventory and the joint economic lot sizing problem models (see reviews by Ben-Daya et al. 2008; and Khouja and Goyal 2008). Other researchers suggested that the inventory-distribution coordination can be achieved by synchronization of the cycle time across the chain stages. In many cases, pure just-in-time (JIT) schedules using a common synchronized common production-replenishment cycle are found not to be optimal. Therefore other developed supply chain models achieve coordination by following the integer multipliers mechanisms in which the cycle time at each stage is an integer multiple of the cycle time of the adjacent downstream stage (Khouja, 2003).

1.4 Benefits of Inventory Coordination

The benefits of inventory coordination and information sharing among the supply chain participants, have received significant attention in the literature. Research findings in this area revealed that information sharing and coordinated inventory replenishments can help reduce the inventory and order costs as well as transportation costs.

Lee et al. (1997) in their investigation on the bullwhip effect in supply chains reported that lack of information sharing can lead to excessive inventory, poor customer service, lost revenues, unplanned capacities, and ineffective logistics. They recommend avoiding managerial independence by integrating various supply chain functions. They also, recommend that firms need to device strategies that lead to smaller batches or frequent replenishments. Exchange of substantial quantities of information among the buyer, supplier, and carrier can increase the efficiency and effectiveness of the supply chain (Carter et al., 1995). Coordinated replenishment can significantly reduce inventory. Inventory reductions have a significant impact on supply chain activities. Lower inventory levels increase operating revenues and reduce the need for costly facilities (Esper and Williams, 2003).
Chen and Chen (2005) investigated the centralized, coordinated replenishment policy and the decentralized replenishment policy in a two-echelon, multi item supply chain. They determined the optimal common replenishment cycle for end items and the integer multiples of the common replenishment cycle for raw materials. They pointed out that a centralized, coordinated replenishment policy was always found to be superior to the decentralized replenishment policy in terms of cost reduction, especially when major setup costs were high.

1.5 Problem Statement

In the past, supply chain production-inventory decisions were not coordinated and information was not shared among the different parties in the supply chain. This lack of coordination leads to weakly connected activities and decisions across the supply chain. Today, timely sharing and coordination of information across the supply chains in addition to the emerging electronic commerce capabilities have changed the way supply chains operate. The global visibility of production-inventory profiles across the supply chain leads to coordinated decisions and in turn to reduced costs and improved customer service.

In recent years, supply chain production and inventory coordination received a lot of attention. Most of the developed models deal with two-stage chains. Even when multi-stage supply chains are considered, most of the developed models are based on restrictive assumptions such as the deterministic demand. Therefore, there is a need to analyze models that relax the usual assumptions to allow for a more realistic analysis of the supply chain. This research extends previous work in the inventory coordination in multi-stage supply chains, and to address the following research questions:

i. How can the supply chain network configured for better coordination?

ii. How to develop algebraic model to drive the optimal replenishment policy for the multi-stage supply chain?
iii. What is the effect of stochastic demand on modeling inventory coordination in multi-stage supply chains?

iv. How can the benefits resulting from inventory coordination be shared among the supply chain partners?

1.6 Objectives of the Study

The proposed research aims at answering questions about how supply chain decisions can be coordinated and optimized to maintain low costs and accepted service levels. The ultimate objective for this research is to develop mathematical optimization models that can be utilized to efficiently coordinate and integrate the production-inventory decisions among the supply chain partners. These partners are suppliers, manufactures, distributors/warehouses, and stores/retailers. However, such collaboration among the supply chain partners requires mutual trust and coordination benefit sharing scheme. Therefore, this research also aims to develop a benefit sharing scheme to entice the production-inventory coordination across the entire supply chain.

To achieve this objective a multi-stage, non-serial supply chain model will be formulated first, and then cost minimization procedures will be proposed to obtain feasible and satisfactory solutions to the problem. Subsidiary objectives to achieve this main objective include:

1. To develop quantitative stochastic models for the multi-stage supply chains. These models will take in to account different inventory coordination mechanism.

2. To develop a mathematical model that can be used to support supply chain strategic policy making such as network reconfiguration.

3. To develop a benefits sharing scheme.
1.7 The Scope of the Study

In this research work we consider the case of a multi-stage supply chain where a firm can supply many customers. This supply chain system consists of suppliers, manufactures, distributors and retailers. The production rates for the suppliers and manufactures are assumed finite. In addition the demand for each firm is assumed to be stochastic. The problem is to coordinate production and inventory decisions across the supply chain so that the total cost of the system is minimized. The model is developed under the following assumptions:

(a) A single product is produced and distributed through a four stage, multi customer, non-serial, supply chain
(b) Production rates are deterministic and uniform
(c) Demand rates are stochastic
(d) Unsatisfied demands at the end retailers are backordered
(e) Ordering /setup costs are the same for firms at the same stage
(f) Holding costs cost are the same for firms at the same stage
(g) Shortage costs are the same for firms at the same stage
(h) A lot produced at stage is sent in equal shipments to the downstream stage.

1.8 Significance of the Study

As mentioned earlier numerous articles in supply chain modeling have been written in response to the global competition. However, most of the developed supply chain inventory models deal with two-stage supply chains. Even when multi-stage supply chains are considered, most of the developed models are based on restrictive assumptions such as of the deterministic demand. But Supply chains are stochastic in nature. Therefore, there is a need to analyze models that relax the usual assumptions to allow for a more realistic analysis of the supply chain inventory coordination.
1.9 Organization of the Thesis

This thesis on multi-stage supply chain inventory coordination is presented in seven chapters. The organization of the report is as follows: chapter 1 is dedicated to give brief introduction the supply chain inventory coordination, statement of the problem, objective of the study, scope of the study, and organization of the thesis.

Chapter 2 provides a review of the research on supply chain inventory modeling. This review included contributions related to two stage supply chains as well as multi-stage supply chain models.

Chapter 3 presents the mathematical description of the problem and the methodology that the researcher used in this research work. It also describes the different inventory coordination mechanisms.

In chapter 4, extensions of the deterministic multi-stage supply chain models are presented. A mathematical model that can help in the integrated design of strategic supply chain networks and the determination of tactical production-inventory decisions is also presented in this chapter.

Chapter 5 describes a stochastic four-stage supply chain model and presents a solution procedure.

Chapter 6 presents the validation of the developed models.

Chapter 7 summarizes this research, outlines the major contributions, and presents its conclusion remarks and recommendations for future research.

1.10 Summary

With the growing focus on supply chain management (SCM), firms realized the need to improve their cost efficiency through closer collaboration among the
chain partners and through high level of coordination of various decisions. This efficient supply chain coordination requires that the flow of products and information among the supply chain members is managed in cooperative manner.

This research study is dealing with the problem of coordinating production and inventory decisions across the multi-stage supply chain so that the total cost of the system is minimized. For this purpose, we develop mathematical models to deal with different inventory coordination mechanisms between the chain members.
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