Assessing the Effects of Transshipments on Profit in a Two-echelon Supply Chain

Dissertation

Submitted to Northcentral University

Graduate Faculty of the School of Business and Technology Management
in Partial Fulfillment of the
Requirements for the Degree of

DOCTOR OF PHILOSOPHY

by

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Prescott Valley, Arizona
August 2010

APPROVAL PAGE

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Abstract

Inventory costs represent a significant portion of a company's total cost of doing business. The problem addressed in this quantitative experimental study is how demand uncertainty and the amount of inventory held affects a business's ability to minimize cost, maximize profit, and meet customer service levels. Excess inventory increases carrying costs while deficient inventory levels result in poor customer service and lost sales. Demand uncertainty makes it difficult for a business to determine optimum inventory levels. An increasing number of businesses have developed inventory management policies that pool inventory, referred to as *transshipment*, to maximize profit, meet customer demand, lower inventory costs, and address demand uncertainty. The purpose of this study was to model the relationships between transshipment procedures and the supply chain to assess the impact that transshipments have on a business's ability to minimize inventory costs, maximize system profit, provide adequate customer service levels and address demand uncertainty. Two inventory management policies developed by the researcher were used to assess how well transshipments minimize inventory cost, maximize system profit, and meet customer service levels. Pseudorandom demand data was used to assess the performance of the inventory policy models. The model output underwent comparative numerical and statistical analysis to assess the relationships between transshipment and system profit in a two-echelon supply chain. Non-parametric Wilcoxon tests showed the difference in system profit between the two inventory policies was significant ($p < .001$). Test results indicated that the occurrence of random demand after transshipment had a significant impact on system profit ($p < .006$), and the use of incentives to encourage transshipment did not have a significant impact on system profit

($p < .871$). A benefit of the research may be the development of a methodology for assessing inventory management policies that employ transshipment to manage inventory. Findings within this study may give supply chain managers insight into the effectiveness of transshipment as a means of managing inventory to maximize system profit. Expanding this study to assess the use of transshipment in more complex supply chains would better assess the value of transshipment as an inventory management tool.

Acknowledgements

I wish to thank my wife and best friend, Lisa Greenburg, for her love, understanding and support. I thank my children Kate, Emily, and Claire for their support, understanding, and encouragement as I pursued my Ph.D. I would like to give a special thank you to the chair of my dissertation committee, Dr. James Neiman, who stepped in to take over as committee chair in the later stages of this process. He provided the guidance and counsel that made it possible for me to complete dissertation. I would also like to thank Dr. Jaime Klein and Dr. Robert Levasseur for serving on my dissertation committee. There honest feedback and knowledge of formatting requirements was crucial in navigating through the process. I would also like to thank my faculty advisor, Jennifer Benacci, who provided exceptional support and guidance. I could not have made it through the school reviews without their help.

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Chapter 1: Introduction

The problem of determining correct inventory levels to minimize cost and maximize profit becomes difficult when demand is uncertain and no prior demand history for inventory exists (Holsenback & McGill, 2007). High levels of customer service often require correspondingly high levels of inventory (Qin, 2005). Holsenback and McGill identified two significant challenges facing businesses: (a) balancing the efficiency and responsiveness of inventories to provide a high level of customer service without accruing excessive investment in inventory, and (b) optimizing inventory levels to maximize profit. The simultaneous management of inventory and customer service is important because they both directly influence a business's ability to maximize profit (Chou, Sim & So, 2006; Dong & Rudi, 2004; Zhang, 2005).

Inventory levels are necessary in a business because they (a) improve customer service and increase sales, (b) reduce purchasing and transportation costs, and (c) provide protection and continuity of operations in case transportation problems arise or there are variances in demand (Stock & Lambert, 2001; Qin, 2005). Several authors (Ballou & Burnetas, 2003; Chiou, 2008; Grahovac & Chakravaty, 2001; Holsenback & McGill, 2007) stated that inventory costs affect the financial performance of many businesses and can directly reduce profit. Ballou and Burnetas (2003) argued that to be competitive, a business must effectively manage inventory demand uncertainty and minimize inventory levels to control costs. Chiou (2008) found it difficult to establish initial inventory levels to support new markets where no demand history for a product existed. A review of literature cited in this research revealed the pooling of inventory, commonly referred to as *transshipment*, was considered to be a cost-effective method of addressing uncertain demand, meeting customer service standards, and reducing inventory levels (Axsater, 2003; Ballou & Burnetas, 2003; Chou et al., 2006; Dong & Rudi, 2004; Grahovac & Chakravaty, 2001; Huang, Chen & Wu, 2007).

The research reviewed for this study examined the use of transshipment to manage inventory levels up to the point of transshipment but failed to consider how demand that occurs after transshipment contributes to cost and profit. Research generally assumed that transshipments occur as needed (Axsater, 2003; Ballou & Burnetas, 2003; Chou et al., 2006; Dong & Rudi, 2004; Grahovac & Chakravaty, 2001; Porteus, 2002; Wong, Van Houtum, Cattrysset, & Van Oudheusden, 2005) and failed to consider the case where independently operating supply points did not freely share excess inventory and may need to be enticed to do so through an incentive. This research presented two inventory management policies, developed by the researcher, that incorporated inventory model cost methodology described by several authors (Ballou & Burnetas, 2003; Himden, Ben Said & Ghedira, 2007; Holsenback & McGill, 2007; Porteus, 2002; Stock & Lambert, 2001). The study used inventory management policies to assess the impact of transshipment on profit, to assess the effect on system profit of random demand occurring at a donor supply point after it has transshipped inventory, as well as the effect of transshipment incentives on system profit.

The remainder of this chapter contains a brief background on the importance of inventory management as it related to profit. Following the background there is a presentation of the problem and purpose of the research, along with the theoretical framework, research questions, and nature and significance of the study. The chapter concludes with a summary and a brief introduction of the literature review presented in Chapter 2.

Background

To be competitive, businesses must be able to satisfy customer demand when and where the demand is presented or they will risk losing a customer's business. A primary objective of most businesses is to maximize profit while satisfying customer's service expectations (Pindyck & Rubinfeld, 2005). Businesses maintain product inventory to help ensure they satisfy customer demand. Managing product inventory presents two conflicting business goals for managers: (a) minimizing the amount of capital tied up in inventory, and (b) when an order is received maximizing the ability to satisfy demand with on-hand inventory. Holsenback and McGill (2007) determined that inventory could be the largest operating expense for a business, and properly managing that expense is critical to optimizing productivity and profitability.

Profit over time could serve as an index to evaluate a business's performance. In many businesses, effective management of inventory made profit maximization possible (Pindyck & Rubinfeld, 2005). Stock and Lambert (2001) stated the cost associated with the quantity of inventory stored represents one of the highest costs to a business. They argued that a firm's inventory policies could have a significant impact on profitability. Several important questions were addressed in this dissertation regarding the effects on system profit facing business managers: (a) the effect of transshipment on system profit, (b) the effect that random demand occurring after transshipment has on system profit, and (c) the effect that the use of incentives for transshipment have on system profit.

The management of inventory in a supply chain could be especially challenging in environments characterized by low-demand rates, expensive items, and requirements for high levels of customer service (Saetta & Tiacci, 2003). An increasing number of businesses have employed strategies that promote inventory sharing among the dealers in their distribution network as a method of reducing costs associated with high inventory levels and improving profit (Huang et al., 2007). Multiple authors (Ching, Yuen, & Loh, 2003; Cohn & Barnhart, 2001; Rudi, Kapur, & Pyke, 2001; Saetta & Tiacci, 2003; Wong et al., 2005) employed inventory management policies and models that incorporate the pooling or sharing of excess inventory, particularly in decentralized supply chain networks. The literature review documented the practice of using transshipment to reduce inventory levels while meeting standards of customer service. Federgruen and Heching (1999) concluded sharing inventory among supply points produced major cost benefits.

One approach used to model inventory policies was to simplify the problem and assume that demand processes were known or were easily estimated (Ballou & Burnetas, 2003; Cohn & Barnhart, 2006; Dong & Rudi, 2004; Ching et al., 2003; Huang et al., 2006). Introducing a new product into a new market creates significant management challenges because the demnd is often unknown (Porteus, 2002). The literature search revealed that researchers performed simplified evaluations of the benefit of transshipments without taking into account the complex interactions of independent supply points that operate to maximize their own profit rather than cooperate to maximize the profit of the supply chain as a whole (Axsater, 2003; Dong & Rudi, 2004; Himden et al., 2007; Huang et al., 2006).

Inventory management in a supply chain involved coordinating the distribution of inventory to satisfy customer demand in the most cost-effective manner (Stock & Lambert, 2001). Axsater (2003) and Himden et al. (2007) examined the importance of supply chains being able to meet expected standards of customer service. Axsater, Himden et al., Porteus (2002), and Zhang (2005) emphasized the utility of employing mathematical models as decision aids in developing effective inventory policies. A weakness of these models was that they failed to address the occurrence of random demand or the provisions for estimating initial inventory levels when no demand history for an inventory item exists. What are neede are decision tools that can assess inventory policy in the face of random demand.

The management utility of inventory decision tools is evident when one considers the estimate by Gaur, Fisher, and Raman (2005) that the total inventory investment of all U.S. retailers averaged $449 billion during 2003 with inventory representing on average 36% of total assets and 53% of on-hand assets for retailers. For 2007, Dedeke and Watson (2008) estimated that the total inventory investment of all U.S. retailers averaged over $496 billion. These figures show inventory costs accounted for a significant portion of retail assets and emphasized the importance of effectively managing inventory to minimize costs.

Problem Statement

This quantitative experimental study addressed the problem of how demand uncertainty and the amount of inventory held by a business directly affected that business's ability to maximize profit and meet required levels of customer service and availability. Excess inventory levels increased carrying costs while deficient inventory levels resulted in poor levels of customer service and lost sales. Demand uncertainty made it difficult for a business to determine accurately the optimum inventory levels it should maintain. According to Holsenback and McGill (2007), inventory costs could represent one-third to one-half of a company's assets and account for a significant portion of the total cost of doing business. To ensure customer satisfaction, inventory was necessary because the availability of the demanded product is often time-sensitive and requires a high degree of availability (Zanoni, Ferretti, & Zavanella, 2005).

Due to the cost of holding inventory, business managers found it difficult to set planned inventory levels high enough to guarantee that 100% of the demand was satisfied from stock (Ballou & Burnetas, 2003; Holsenback & McGill, 2007; Huang et al., 2007). Demand uncertainty and the costs associated with holding inventory had a direct effect on a business's profit by tying up cash flow (Himden et al., 2007; Rudi et al., 2001). All of these researchers have noted the importance of developing and implementing effective inventory policies that assist managers in minimizing inventory costs, meeting expected standards of customer service, dealing with random demand, and maximizing profit.

Purpose

The purpose of this quantitative experimental study was to assess the impact that transshipments had on a business's ability to minimize inventory costs, maximize system profit, provide adequate customer service levels and address demand uncertainty by mathematically modeling two inventory management policies developed by this researcher. The cost and profit data generated from the models underwent comparative numerical analysis to determine which inventory management policy produces the lowest cost and greatest system profit. The Wilcoxon Matched Pairs test statistically tested the ability of an inventory management policy employing transshipment to maximize system profit when the supply points receive post transshipment demand. The test assessed the impact of incentives to induce participation in transshipment and the differences in system profit. Random demand for inventory served as the independent variable in the inventory policy models to generate the values for the dependent variables of cost and profit. Using the Gaussian distribution to determine sample size, a sample of 390 pseudorandom integer values simulated demand for inventory at each supply point.

Theoretical Framework

Increasing globalization of business activities following World War II created the need to coordinate effectively supply chain inventory activities. A goal of this study was to develop a research framework that provided a useful tool for assessing the ability of inventory policies that employed transshipment to maximize profit and minimize cost. The theoretical framework presented an approach for mathematically modeling the effectiveness of two proposed inventory management policies for a two-echelon supply chain. An approach was used that adds to the current knowledge of supply chain management by quantitatively comparing and assessing the impact of transshipment on system profit, considering the effect on system profit of random demand occurring after transshipment, and by assessing the impact of incentives to participate in transshipment on system profit.

The assessment determined the effectiveness of transshipments by modeling inventory management policies that incorporated randomly occurring demand and used incentives to encourage participation in transshipments. Two significant challenges facing businesses were examined: (a) balancing the efficiency and responsiveness of inventories to provide a high level of customer service without accruing excessive investment in inventory, and (b) optimizing inventory levels to maximize profit. During the past decade, the field of supply chain management has benefitted from the employment of mathematical modeling and simulation to represent the relationships describing the dynamics of inventory in supply systems (Winston, 2004).

Disney, Farasyn, Lambrecht, Towill and Van de Velde (2006), Gupta and Maranas (2003), Kang and Gershwin (2005), Liu, Liu, and Yao (2004), and Santoso, Ahmed, Goetschalckx, and Shapiro (2005) demonstrated the usefulness of modeling demand processes and inventory replenishment policies through the use of mathematical models. A common approach in their research was to simplify the problem by assuming that demand was discrete, normally distributed, and known. The authors advocated the use of assumptions to simplify the problem of defining and solving the key dynamics of a complex supply chain whose goal was to minimize the overall inventory in the system while meeting the required service level.

Liu et al. (2004) argued the use of simplifying assumptions enabled the development of techniques that delivered accurate estimates. The approach in this study focused on using inventory management policies to assess the ability of transshipments to minimize inventory costs and maximize system profit. Using this approach, the assumptions developed accurately modeled the actual dynamics and interactions of the supply chain. The theoretical research framework presented in this study provided fresh insights for inventory management and underscored the premise that effective inventory policy could benefit from the ability to model dynamic and interdependent relationships.

Research Questions

The study of inventory management provides businesses and managers with knowledge to implement effective inventory policy in supply chains. The knowledge of whether a specific inventory management policy is effective in minimizing cost and meeting required standards for customer service better helps managers and decision makers to maximize supply chain profit. Two goals of determining effective policy are to identify the true cost of inventory and to develop and employ measures that allow managers to make effective decisions regarding inventory levels that control costs. This study assessed the impact of transshipment on profit in a two-echelon supply chain by examining two inventory management policies developed by the researcher. The performance of these policies was evaluated in terms of inventory costs, customer service levels, and system profit by examining the following research questions and hypotheses, which could result in enabling managers and decision-makers to make informed decisions about the allocation of inventory levels to control costs and maximize profits.

Q1. Does an inventory management policy that uses transshipment achieve higher system profit than an inventory management policy that does not use transshipment?

Q2. Does the occurrence of random demand at a supply point after it has donated inventory for transshipment lead to decreased system profit?

Q3. Does the use of incentives to induce participation in transshipment lead to decreased system profit?

Hypotheses

The following are the null and alternate hypotheses that were the focus of the research.

$H1_0$. There is no significant difference in total system profit when an inventory policy using transshipment is compared to an inventory policy that does not use transshipment.

$H1_a$. There is a significant difference in total system profit when an inventory policy using transshipment is compared to an inventory policy that does not use transshipment.

$H2_0$. There is no significant decrease in system profit when random demand occurs at a supply point after it has donated inventory for transshipment.

$H2_a$. There is a significant decrease in system profit when random demand occurs at a supply point after it has donated inventory for transshipment.

$H3_0$. There is no significant decrease in system profit when incentives are used to induce participation in transshipment.

$H3_a$. There is a significant decrease in system profit when incentives are used to induce participation in transshipment.

Nature of the Study

This quantitative experimental study mathematically modeled the ability of transshipments to minimize inventory costs and maximize profits by using two inventory management policies. Using simulated random demand to exercise the policy models, each model's ability to address random demand, provide high levels of customer service, minimizes costs, and maximize system profits in a simple supply chain composed of two-echelons was measured and assessed. The variables examined in this study were random demand, inventory cost, incentive cost, and profit. The inventory policy cost and profit data generated from the modeling underwent numerical comparative analysis to assess the performance of the inventory management policies. The Wilcoxon matched pairs test was applied to statistically evaluate the results of the modeling in order to address the research questions and hypotheses.

A 390 element set of pseudorandom demand values for each supply point was mathematically generated using procedures suggested by Winston (2004), Yi (2005), and Zhang (2005). The demand values were input into each inventory management policy model to exercise the model and generate output to provide a basis for comparative analysis. The standard inventory management policy served as the baseline policy. It did not employ transshipments; the supply points operated independently to maximize their individual profit. The shared inventory management policy employed transshipments as a means of sharing excess inventory between supply points in the supply chain to control inventory costs. In this policy, a central decision-maker was responsible for coordinating inventory sharing among independent supply points to maximize supply chain profit. In the shared policy, an incentive formula for profit sharing developed by this researcher was used to encourage the independent supply points to participate in transshipments.

The design study was chosen because experimental designs have an advantage over quasi-experimental and non-experimental methodologies for determining causation (Trochim, 2006). Winston (2004) stated that mathematical modeling was well-suited to the process of creating a representation of some phenomenon in order to gain a better understanding of that phenomenon. Mathematical models required researchers to be precise and unambiguous and allow comparisons of competing theories (Mazure, 2006).

While there was a good deal of research focusing on transshipments as a means of reducing inventory levels the literature review for this research did not identify any empirical research for the case where a supply point with excess inventory shared inventory with a inventory deficient supply point and then received demand and may not be able to fill it with on-hand inventory. No empirical analysis was identified that addressed the impact that incentives used to encourage transshipment had on system profit. The study used numerical and statistical analyses of model results to assess the impact of: transshipment on system profit, the impact random demand occurring after transshipment had on system profit, and the impact that the use of incentives for transshipment had on system profit.

Significance of the Study

A significant problem facing managers was how to manage inventory levels to minimize cost and maximize profit. To establish the proper level of inventory to meet customer demand requirements while maximizing profit involved weighing efficiency, responsiveness, and customer service levels against inventory costs (Ballou & Burnetas, 2003; Stock & Lambert, 2001). The presence of random demand for inventory made it difficult to establish initial inventory stocking levels and created a difficult problem that could affect profit (Ballou & Burnetas, 2003). Holsenback and McGill (2007) found that inventory costs could represent one-third to one-half of a company's assets. They also found that companies with high inventory holding costs could end up paying for inventory twice in slightly more than two years. Ballou and Burnetas estimated that 25% of all unmet demand, referred to as *stockouts*, resulted in lost sales.

In cases where a supply point experienced unmet demand the potential existed for all or a portion of the demand to be satisfied through transshipments from another supply point in the network. The total cost of transshipment was a major element to consider when determining if transshipments were an effective means of solving inventory shortages and in preventing stockouts and lost sales. In a competitive environment, incentives may be needed to induce independently operating supply points to participate in transshipment.

The current research did not address several important aspects of transshipments that could lead to poor inventory management results: (a) the effect of demand occurring after a supply point had been incentivized to participate in transshipment, and (b) the effect that the transshipment participation incentives had on system profit. Inventory pooling and transshipment of stocks has mostly been analyzed in a single-echelon setting (Axsater, 2003; Bell, 2001; Dong & Rudi, 2004; Himden et al., 2007; Rudi et al., 2001; Zhang, 2005; Ziya, 2004). This study research was expanded from previous research with the consideration of a two-echelon setting. Unlike the majority of current research, this study contained an expanded examination of the total cost of sharing inventory between supply points by considering the effects of random demand occurring after transshipment and the effects of incentives on system profit. The shared inventory model included not only the costs of transshipment and of incentivizing supply points to share excess inventory, it also provided a method to numerically address the cost resulting from unanticipated demand occurring at a supply point.

Information gained from this research provided managers with an approach that could be used to model their inventory levels to maximize system profit. Simulation was used to provide insight into the integrated analysis of inventory and transshipments so that managers could have a better understanding of the behavior of the supply chain system. Although the study was based on a simple supply chain composed of two echelons, the findings should ultimately be applicable to larger supply chain systems where managers make decisions regarding initial inventory demand management in a supply chain with independent entities whose decisions affect the performance of the overall system. Thus, an analysis of the inventory management policies presented in this study could provide evidence to support or reject the use of transshipment as a management strategy. These findings may significantly alter the perception of many managers and practitioners and provide them with a better understanding of how to successfully develop and implement an inventory management policy to obtain the best results.

Definitions

The following key terms were considered to be crucial and unique to an understanding of the proposed research.

Fill Rate. The fill rate was defined as the percentage of demand that was satisfied as a percentage of the total demand (Ballou & Burnetas, 2003). The fill rate measure defined the true service level to customers by comparing a customer's preferred order quantity to the actual quantity they physically received on the originally requested delivery date. The fill rate could be calculated using the formula: Fill Rate (%) = (Received Units/Ordered Units) x 100.

Inventory Holding Cost. Holsenback and McGill (2007) defined inventory holding cost as the variable cost of keeping inventory on-hand to immediately satisfy customer demand. They associated holding costs with the quantity of inventory stored which represents one of the highest costs of logistics. The authors further argued that the effect of inventory holding costs are far-reaching, providing a survey of literature that estimates holding costs, as a percentage of inventory, to be between 12% and 35%.

Optimization. Winston (2004) defined optimization as a mathematical procedure for determining optimal allocation of scarce resources. Optimization was described as the mathematical process of obtaining a maximum objective function value or minimum objective function value from the objective region. Optimization has found practical application in almost all facets of business, from advertising to production planning.

Stochastic Demand. Stochastic was described as synonymous with random. A stochastic process described the relationship between random variables (Winston, 2004). The term stochastic was used to show that a particular subject was seen from a point-of-view of randomness. Porteus (2002) defined stochastic demand as having non-deterministic behavior and resulting from both known and unknown causes.

Stockouts. Axsater (2003) defined stockouts as the condition of demand occurring at a warehouse and the on-hand inventory being insufficient to satisfy the demand. Chou, Sim, and So (2006) described stockouts as a shortage of inventory at one supply location that required transshipment of inventory to meet the demand at another supply point. Ballou and Burnetas (2003) defined stockout as demand that could not be filled immediately. Stockouts were likely to occur when product availability rates were set at less than 100% to avoid inventory carrying costs.

Supply Chain Management. Supply chain management involved the systematic approach of managing the flow of information, material, and services in fulfilling a customer demand. Ballou and Burnetas (2003) defined supply chain management as the oversight of materials, information, and finances as they moved in a process from supplier to manufacturer to wholesaler to retailer to consumer.

System Profit. System profit represented the integrated and combined profit from all the separate areas in a specific system to create a total measure of profit. Blanchard (2004) claimed that system profit should be aggregated, integrated, planned, tracked, analyzed and controlled by one central source.

Transshipments. Rudi, Kapur and Pyke (2001) defined transshipments as the practice of transferring stock from a distributor who had surplus stock to another that had a stock shortage. They went on to specify that transshipments represented voluntary trades between firms. Huang, Chen and Wu (2007) identified transshipments in the context of demand not being met by a retailer because of a stockout and an emergency lateral replenishment needing to be obtained from one or more retailers with stock on-hand. Himden, Ben Said, and Ghedira (2007) saw transshipments as an inventory collaboration method of transferring inventory items between locations.

Two-echelon Supply Chain. Huang, Chen, and Wu (2007) referred to a supply system composed of a supplier and independent retailers as a two-echelon system. Ching, Yuen, and Loh (2003) expanded the term to mean a supply system composed of a main depot and *n* identical inventory systems.

Summary

This quantitative experimental study focused on assessing the impact of transshipment on profit in a two-echelon supply chain. Based on a review of literature, it became clear that recent supply chain analysis had not addressed three critical and interrelated topics: (a) the ability of transshipments to maximize system profit, (b) the impact that random demand occurring after transshipment had on system profit, and (c) the impact that incentives to participate in transshipments had on system profit. Holsenback and McGill (2007) described the significant challenges of balancing inventories to provide a high level of customer service without accruing excessive investment in inventory and optimizing inventory levels to maximize profit. The authors also estimated that the true value of inventory holding costs could be 50% or more of the value of the inventory and that properly managing inventory was crucial to optimizing productivity and profitability. Profit was often used as an index by which a business's performance was evaluated over time (Pindyck & Rubinfleld, 2005).

The importance of inventory management comes from the fact that reductions in inventory had a direct effect on the profitability of the business (Ballou & Burnetas, 2003). From the customer's perspective, the availability of the demanded product was often time-sensitive and required a high degree of availability (Zanoni et al., 2005). A review of literature revealed that transshipment was thought to be a cost effective method of dealing with demand, satisfying customer service levels, and reducing inventory levels (Axsater, 2003; Ballou & Burnetas, 2003; Chou et al., 2006; Dong & Rudi, 2004; Grahovac & Chakravaty, 2001; Huang et al., 2007). Current literature assessing the effectiveness of transshipments in two-echelon supply chains failed to consider several important and interrelated problems: (a) establishing initial inventory levels in a supply chain containing independently operating supply points when no demand history existed for a new product, (b) random demand occurring at independent supply points after transshipment occured and the effect it had on system profit, and (c) incentives that might be required to entice the independent supply points to forego the potential risk of participating in transshipments.

In this study modeling and simulation of two inventory management policies developed by the researcher was used to present a unique assessment on the effectiveness of transshipments in minimizing cost, maximizing system profit, and meeting required levels of customer service and availability. Modeling and simulation of the inventory policies was used to provide insight into the integrated analysis of inventory and transshipments so that managers can have a better understanding of the behavior of the supply chain system.

Chapter 2: Literature Review

This quantitative experimental study assessed the impact that transshipments had on a business's ability to minimize inventory costs, maximize system profit, provide adequate customer service levels and address demand uncertainty by mathematically modeling two inventory management policies developed by the researcher. Numerical and statistical analysis were used to assess the impact of random demand, post transshipment demand, and the use of transshipment incentives on system profit. This chapter contains a review of literature related to inventory management policies that used transshipment to manage inventory levels and achieve specific levels of customer service while minimizing cost and maximizing profit levels in a two-echelon supply chain. The literature review began with a historical summary of developments in inventory management theory. Following the historical summary, a review of recent literature was presented which focused on the employment and analysis of transshipment as a means of managing inventory levels.

The literature review contained a critical analysis and synthesis of research that provided the context for the assessment of the impact of transshipment on profit in a two-echelon supply chain and was comprised of five sections: *Historical Background; Inventory, Customer Service, and Cost; Stochastic Demand and Transshipment Theory; Incentives for Transshipment; and Mathematical Modeling and Simulation of the Supply Chain.* A summary of each section's key points was presented at the end of the section. At the end of the literature review, a general summary section was presented that summarized the key points presented in this chapter. Literature sources included unpublished doctoral dissertations, academic working papers, and peer reviewed articles in professional and academic journals, published conference papers, and graduate text books.

The search strategy used for this study was designed to identify recent and historical literature that addresses the growth of inventory management theory as a tool to maximize profit. The importance of incorporating demand uncertainty as a means of effectively meeting customer demand was also emphasized in the search in order to provide research material describing relationships that might exist between inventory, customer service, and cost. A goal of the literature search was to provide a basis for understanding the importance of random demand on inventory policy and to identify current literature addressing the effectiveness of transshipments as an inventory management tool. Another goal of the literature search was to identify research involving mathematical modeling of inventory management and any potential utility and drawbacks of applying modeling and simulation to address the research problems. The purpose being to identify research for study that focused on mathematical modeling and simulation of inventory management policies to achieve profit optimization that was applicable to the methodology proposed in this dissertation.

Historical Background

The problem of dealing effectively with demand uncertainty as a means of controlling inventory levels, and minimizing costs in order to maximize profit, has received a great deal of attention from supply chain researchers. The literature in the area of inventory management was vast, beginning with articles in the late 1940s. Following World War II the interest in synchronizing procurement, demand forecasting, inventory management, and transportation of inventory took on greater and greater importance as nations attempted to rebuild their industrial capacity that had been destroyed or seriously depleted during the war (Chase & Aquilano, 1992; Chase, Jacobs & Aquilano, 2006). As manufacturing and economic growth flourished during the 1950s supply chain management developed as a specific discipline (Cartlidge, 2004).

Cartiledge (2004), Chase and Aquilano (1992), Chase et al. (2006) discussed how inventory and supply chain management was developed to enable manufacturing companies to increase their competitiveness, market share, and profitability by applying a systems approach to management. The new principles of supply chain management such as minimizing the costs of production on a continuing basis, introducing new technologies, and improving quality were championed by management consultants (Chase et al., 2006). In the early 1950s Dr. W. Edwards Deming was instrumental in introducing statistical management techniques to Japan where the Japanese car manufacturing industry and in particular Toyota achieved success in improving quality and earning a reputation for quality goods.

One of the first successful examples of integrating inventory management as a way to increase profit in a production environment occurred in post World War II Japan. The Japanese production engineer Tai-Ichi Ohno was credited with structuring the Toyota Production System as an integrated framework which emphasized the importance and integration of suppliers and inventory into a comprehensive system. In the late 1940s, Ohno experimented with various ways of setting up the Toyota automotive assembly line equipment to produce needed items in a timely manner.

During a 1956 visit to the United States, Ohno was impressed with the operation of supermarkets and the way the supermarkets supplied merchandise in a simple, efficient, and timely manner. Based on his observations, Ohno developed a pull system production line where the current line was driven by the needs of the following lines. Under the pull system the production line received only those items needed for immediate production. On the preceding line only the replacement items for the ones that had been selected for the following line were produced. This pull system was a radical departure from the conventional push systems, which were driven by the output of preceding lines.

Chase et al. (2006) discussed how a number of process and management tools were developed to create a systematic framework for production operations. The best known of those tools was the Japanese Kanban or card system, which provided for conveying information in and between processes on instruction cards. A key tenet of the pull-type system was the elimination of waste through cooperation with suppliers. Waste was identified as activities that created no value, such as; defects in products, overproduction of goods, large inventories of goods, unnecessary processing, and movement of people and goods.

In the inventory pull-type system, good communications with suppliers were required to ensure that production was initiated by actual demand, rather than by plans based on forecasts. The inventory pull system was in direct contrast to the predominantly employed inventory push-type system. In the push-type system, large volumes of materials and components were produced, transported and stored ahead of demand. The requirements resulted in large inventory stocks and large amounts of capital being tied up in inventory. The inventory pull-type system advocates that as excess inventory was removed from the supply chain, value was added to the process leading to lower costs, shorter construction periods and greater profits (Chase et al., 2006).

In the 1960s there was an extensive development and application of operations research tools such as simulation, waiting-line theory, decision theory and mathematical programming to support inventory management and control in the manufacturing sector (Chase et al., 2006). These developments were the beginning of the shift from inventory management to inventory optimization. During this time, IBM's Joseph Orlicky developed Material Requirements Planning (MRP) to ensure that the flow of raw materials and in-process inventories matched the manufacturer's production schedules for finished products (Chase & Aquilano, 1992). Prior to MRP, production of every part and end item was triggered by the inventory falling below a given level or reorder point. The benefit of MRP was that it allowed each of the manufacturing units to dictate to their supplier what parts were required and when.

The MRP system was used to address the problem of determining how many of a particular component was required knowing the number of finished products. Advances in computer hardware made it possible for the MRP systems to take a bill of materials for a specific finished product and develop it into a production schedule and purchasing plan for the required components. The MRP system reduced the lead time in products design, improved the efficiency in procuring raw materials and components while quickly responding to individual customer requirements. Though not a perfect system, the application of MRP provided improved management capabilities. Gunasekarana and Ngai (2005) examined how the proliferation of products and uncertainties over demand resulted in difficulties in MRP, leading to high inventories and poor customer service levels. They noted that MRP suffered from design concepts. What was needed was a system that had the ability to differentiate between products to reduce the impact of inaccurate forecasts and the ability to shorten order response times in a supply chain environment.

In the 1970s there was a widespread increase in the use of computers in business. By the 1980s, the next generation of MRP, known as Manufacturing Resources Planning, or MRP II, was developed for planning all manufacturing resources, including those related to operational planning, financial planning, business planning, capacity requirements planning, and master production scheduling. During this time, new emphasis was placed on increasing productivity and decreasing cost by actively managing inventory levels throughout the entire supply chain. In the 1990s advances in computer technology led to the development of Enterprise Resource Planning (ERP). The ERP system took advantage of the newly developing computer client/server information technology architecture making it feasible to integrate the business applications of a corporation with a common data base (Chase et al., 2006).

An important technological advance that facilitated the further development of inventory management processes was the development of high-speed computer networks. These networks improved the communication of information and supported the development of lean production philosophy and the concepts of Just in Time (JIT) and Total Quality Control (TQC) to manage inventory. In this environment inventory took on increased importance as a key cost element in the supply chain. The advances in computer technology increased the ability of researchers to conduct mathematical and analytical research focused on examining fluctuations in demand, identification of optimal storage locations in support of customer demand, and identification of optimal stock levels by location in order to establish optimal inventory ordering policies (Winston, 2004).

Advancements in computer technology also greatly increased the ability to have real time visibility on inventory throughout a system. Teich, Wallenius, and Wallenius (1999) studied how the development of high-speed and low-cost sharing of information through networked databases improved the effective management of inventory in the supply chain. Ching et al. (2003) advocated that in the past decade, computers and the Internet had revolutionized the business practices giving inventory increased importance as a key cost element in the supply chain.

The literature review conducted for this study provided insight into a number of differing views on the development of inventory management. Blanchard (2004) described how supply chain research during the last ten years has concentrated on analyzing and determining how much inventory to carry and where to store it. Supply chain research has included the examination of fluctuations in demand, and the identification of optimal storage locations in support of customer demand, and identification of optimal stock levels by location to establish optimal inventory ordering policies. Contrary to the proponents of JIT inventory management who advocated minimizing inventory levels through tight production, Qin (2005) identified several benefits and tradeoffs of inventory management and concluded that reasonable inventory levels led to an efficient level of service and reduced costs. One widely-used inventory management concept, Vendor Managed Inventory (VMI), required suppliers to stock a minimum level of inventory to ensure that customer demand can be quickly satisfied.

Under the VMI concept, the suppliers retained ownership of the inventory until customer demand pulled the inventory from the warehouse. Ziya (2004) found that not all suppliers were willing to participate in VMI programs because of varying customer demand and the added cost of carrying inventory. Ziya also found that when inventory had short product life cycles, as in the case of mobile phones, supply points were reluctant to own larger than necessary amounts of inventory. Reduced inventory levels increased the risk of not being able to satisfy customer demand. For example; in a push contract the retailer incurred the inventory risk whereas in a VMI pull contract the supplier did.

Summary. Following World War II the interest in supply chain management took on greater importance as nations attempted to rebuild their industrial capacity. The requirement to deal effectively with demand uncertainty, to control inventory levels, minimize costs, and maximize profit led to several key developments in supply chain research. The application of statistical process control methods in the 1940s and 1950s paved the way for the development in the 1960s of MRP technology to aid inventory control in the manufacturing sector. These new technologies reduced the lead time in product design and supported the efficient procurement of raw materials and components to quickly respond to individual customer requirements (Chase et al., 2006).

In the 1980s MRP II was developed to increase productivity and decrease cost by actively managing inventory levels. In the 1990s advances in computer technology led to the development of ERP which made it feasible to integrate the business applications of a corporation with a common data base. The continued development of high-speed computer networks supported the development of lean production philosophy and the concepts of JIT and TQC. In the past decade, computers supported the growth of mathematical and analytical analysis of inventory management theory and problems (Teich et al., 1999; Ching et al., 2003). Computer-supported research has facilitated the mathematical calculations required for examining fluctuations in demand, identification of optimal storage locations in support of customer demand, and identification of optimal stock levels (Winston, 2004). Advances in computer technology greatly improved inventory visibility and supported the development of inventory policies that incorporate new capabilities for managing inventory as a key cost element in the supply chain.

Inventory, Customer Service, and Cost

The literature review for this study highlighted the increasing interest in employing inventory management policies to minimize cost, maximize profit and meet specified levels of customer service. Ziya (2004) studied the percentage of time that customer demand was met with on-hand inventory compared to the percentage of time on-hand inventory was insufficient to meet demand. He examined the ratio of demand met to total demand, referred to as fill rate, and how the fill rate regulated expected sales by taking into account the size of a shortage when it happens. Ziya determined from his research that the size of shortages became important in evaluating expected sales when sales were lost due to insufficient inventory levels on hand. Ziya's conclusions regarding fill rate methodology compared favorably with the research findings of Blanchard (2004) and Holsenback and McGill (2007) who also determined that the fill rate played an important role in customer satisfaction.

Gupta and Maranas (2003) studied how the increasing competitive pressures in the global marketplace coupled with the rapid advances in information technology brought inventory planning into the forefront of most manufacturing and service organizations. Gupta and Maranas' research results generally agreed with Ching t al. (2003) and Ziya (2004) but they followed a different approach than the known demand quantity approach presented by Axsater (2003), and Dong and Rudi (2004) and researched the decision-making process in supply chain networks by decomposing the supply chain activities into time horizons. They concluded that given the constantly shifting and increasing customer expectations' failure to account for significant demand fluctuations could either lead to unsatisfied customer demand translating to loss of market share or excessively high inventory holding costs. Like Bell (2001) and Porteus (2002), Gupta and Maranas emphasized the importance of incorporating demand uncertainty into the planning decisions and concluded that customer demand was what primarily drove most supply chain planning initiatives.

A common theme found in the reviewed dissertation research is that supply chain managers frequently faced the problem of providing high customer service levels while minimizing the accompanying cost of inventory and safety stock. Disney et al. (2006) studied this problem by using a generalized order-up-to inventory policy to measure inventory variance and the customer service levels it generatedS. They quantified the variance in replenishment orders and the variance of inventory levels over time, and demonstrated that high customer service, as measured by fill-rate and in stock replenishments, did not necessarily increase inventory cost substantially. These conclusions by Disney et al. contradict those of Ballou and Burnetas (2003), Blanchard (2004), and Holsenback and McGill (2007) who concluded that inventory levels directly contributed to costs.

Qin (2005) concluded from his research that high levels of customer service often required correspondingly high levels of inventory. His conclusions supported the research presented by Ballou and Burnetas (2003), Blanchard (2004), and Holsenback and McGill (2007) who found that inventory provided a service to the customer by giving an immediate source of supply that buffered the production system from fluctuations in demand. The conclusions of these researchers provided a basis for arguing that marketing and production executives had a fundamental interest in inventory to facilitate setting inventory levels to ensure a suitable customer service level.

Disney et al. (2006) concluded from their research that the financial implications of inventory and customer service problems were often hard to determine, although the benefits of designing replenishment rules to control inventory levels, maintain customer service and set production targets, have been realized for a long time. The authors took a unique approach by studying inventory within the framework of non-competitive behavior and concluded that inventory managers must consider two primary factors when replenishing inventory: (a) replenishment impact on order variability as measured by the ratio of the variance of orders over the variance of demand shown to the supplier, and (b) replenishment impact on the variance of the net stock as measured by the ratio of net stock variance over the variance of demand. The authors determined from their research that the key to designing an effective replenishment policy was balancing inventory and production costs while ensuring an appropriate customer service level. Disney et al. advocated, as did Ballou and Burnetas (2003), Blanchard (2004), and Holsenback and McGill (2007), that the fill-rate be used as a customer service metric because it was popular in industry and was a valid tool to investigate inventory requirements needed to meet a target customer service level. The authors found that setting a target customer service level was often beneficial because it provided the flexibility to set the company's service proposition in the marketplace to minimize holding and backlog costs via the economic stock-out probability.

The review of literature revealed that there was a variety of opinions and approaches for determining the importance and impact of inventory levels. Zanoni et al. (2005) argued that the importance of inventory management had increased in the past decade because of systems availability and high quality after sales service demanded by customers. Ballou and Burnetas (2003) and Qin (2005) focused on the difficulty of managing inventory under uncertain demand, namely the occurrence of stockouts and less than adequate fill rates. Bell (2001) used the framework of a newsvendor problem to discuss the inventory cost implications of stocking one too many items compared to stocking one too few from the perspective of both a customer and vendor. Axsater (2003), Chou et al. (2006), Himden et al. (2007), and Huang et al. (2007) researched distribution networks composed of multiple locations where product was held as inventory.

The common theme expressed in the research conducted by these authors was the perceived value of determining inventory levels by optimizing cost, demand, and customer service. One shortcoming of their approach was the assumption that demand was either known or could be estimated with a degree of accuracy rather than addressing the more realistic assumption of stochastic demand as advocated by several authors (Bell, 2001; Porteus, 2002; Winston, 2004). Bell and Porteus argued that the optimum inventory level should be based on the probability of a stockout being set equal to the ratio of the inventory item's unit cost to its unit price. Axsater (2003), and Grahovac and Chakravarty (2001) followed a different approach by deriving heuristics under the continuous review and Poisson demand settings which they used for estimating inventory requirements.

Ballou and Burnetas (2003) researched common pull-type inventory control systems which established stock levels based on demand, cost, and service-level requirements associated with a specific geographic location. The results of their research supported the theory that localized control could lead to lower inventory levels when compared to push-type stock methods. Ballou and Burnetas argued that the fill-rate was closely linked to carrying costs, a conclusion also supported by Ziya (2004) and Qin (2005). Ballou and Burnetas also examined priority rules for sequencing order filling to minimize transportation costs using by-proximity rules and constant fill rate for all stocking locations. One shortcoming of their research was that the author's simplification of the problem overlooked the possibility of stochastic demand occurring.

Several authors explored the importance of customer service as a means of managing inventory, costs and profit. Vickery, Jayaram, Droge, and Calantone (2003) provided an expanded analysis of inventory levels by examining the relationships between an integrative supply chain strategy, customer service, and overall firm performance. They identified two major dimensions of an integrative supply chain strategy: (a) integrative information technologies, and (b) supply chain integration. The authors chose customer service as a key means of mediating the relationship between integration and firm performance.

Vickery et al. (2003) concluded that the objective of an integrated supply chain strategy should be the synchronization of the final customer's requirements with the flow of materials and information along the supply chain in order to reach a balance between high customer service and cost. The auathors supported the findings of Teich et al. (1999), and Ching et al. (2003) regarding the importance of computer information systems in inventory management. The authors' findings regarding the importance of accurate and timely inventory information also closely align with those of Ballou and Burnetas (2003), Qin (2005), and Zanoni et al. (2005).

The approach used by Qin (2005) and Ziya (2004) Vickery et al. (2003) emphasized the importance of customer service as a means of managing cost and risk in the performance of the entire system. They argued that transaction costs could be described as consisting of two components: (a) coordination costs, or the direct costs of integrating decisions between economic activities; and (b) transaction risk, or the cost associated with the risk of being exploited in the relationship. The authors concluded that a positive relationship existed between supply chain integration and customer service and a direct positive relationship between customer service and financial performance.

The approach taken by Gunasekarana, Patel, and McGaughey (2004) focused on the effect of customer satisfaction as a means of optimizing inventory levels. They advocated that customer satisfaction was the key element to measuring and improving inventory and was a desirable method to increase competitiveness. They observed that because inventory delivery took place in a dynamic and ever-changing environment, the study and subsequent improvement of a distribution system was difficult. Their main conclusion was that with customer service requirements constantly increasing, effective management of inventory in the supply chain was crucial because without a contented customer, the supply chain strategy could not be effective. The authors emphasized that to assess supply chain performance, metrics must center on customer satisfaction.

Another recurrent theme observed in the literature review was the concern of cost associated with using safety stock as an inventory buffer to ensure that required levels of customer service could be met. Holsenback and McGill (2007) presented a detailed assessment of inventory costs from a cost accounting perspective and advocated that inventory holding cost and safety stock inventory were critical to the effective management of inventory. They argued that few managers know the true value of inventory holding cost, and that few realize the true affect that inventory management decisions have on profit. Holsenback and McGill proposed that inventory holding costs should be based on both an item's price-dependent and quantity-dependent components and should consider both fixed and variable cost components.

Bollapragada, Rao, and Zhang (2004) used an economic approach to study the problem of distributing inventories at different levels in a two-echelon supply chain consisting of components and finished goods. The authors argued that the goal of positioning inventory was to meet customer service targets without violating budget constraints on inventory investment when uncertainty exists in both supply and demand. The authors developed and presented two models which accounted for supply uncertainty to determine optimal base stock levels for components and finished products. The authors suggested a solution to minimize total inventory investment while still achieving the desired customer service level and incorporate an approach similar to that of Bell (2001) and Porteus (2002). Their solution was one of the few identified in the literature review that incorporated demand uncertainty as a key component in modeling supply chain activity.

Bollapragada et al. (2004) developed mathematical models to demonstrate that under both demand and supply uncertainty the optimal component stock level was a convex-decreasing function of the stock level of finished products. The author's provided insights from their research on how stock positioning in two-echelon supply chain systems changed with problem parameters by computing base-stock inventory levels under both supply and demand uncertainty in a two-echelon system with a customer service level constraint. The methods presented by the authors lent themselves to sensitivity analysis which could be used to establish a cause and effect relationship among the variables of interest.

Kang and Gershwin (2005) expanded the research of Bollapragada et al. (2004) by discussing the use of elevated inventory levels as a protection against uncertainties such as demand and supplier lead time. From their research they found that companies often used higher inventory levels as a buffer against uncertainty. Liu et al. (2004) provided a detailed assessment of the effect of uncertain demand on the performance of a system, including its service level in terms of fill rate and how this affected a business's bottom line in. Kang and Gershwin's conclusion that inventories could be used to hedge uncertainties and achieve a specific service level closely paralleled the conclusions of Ballou and Burnetas (2003). Kang and Gershwin opined that because inventory placed at different locations usually incurred different costs and resulted in different service levels for end customers, the efficient allocation and control of inventory assets presented both opportunities and posed challenges to companies.

Summary. The literature reviewed in this section highlighted the fact that increasing competitive pressures in the global marketplace coupled with the rapid advances in information technology have brought supply chain planning into the forefront of most manufacturing and service organizations. While the majority of the authors acknowledge the importance and difficulty of incorporating demand uncertainty into the inventory planning decisions there were conflicting opinions and a variety of recommended approaches. A number of methods and approaches for managing inventory were proposed that range from focusing on inventory cost to focusing on customer service levels. A common theme was the acknowledgement of the problem of providing high customer service levels while minimizing the accompanying cost of inventory and safety stock. The importance of managing inventory to control costs was seen in the variety of inventory management techniques that were presented to minimize supply and demand imbalances in the supply chain.

The reviewed literature examined several distribution networks composed of multiple locations where product inventory levels were determined by optimizing cost, demand, and customer service levels. One observed shortfall was the majority of the reviewed research focused on single instead of multiple echelon systems. The research reviewed indicated another theme: that a positive relationship existed between supply chain integration, customer service, fill-rate, and financial performance. The majority of the research advocated that inventory holding cost and inventory levels were critical to the effective management of inventory. Several researches who investigated inventory as a buffer against uncertainty and as a means of achieving service level in terms of fill rate were discussed. The research indicated that while inventories could be used to hedge uncertainties and achieve a specific service level the efficient allocation and control of inventory assets presented both enormous opportunities and posed a great challenge to many companies.

Stochastic Demand and Transshipment Theory

The importance of optimal supply chain performance is reflected in the following statement by Gerard P. Cachon (2003):

> Optimal supply chain performance requires the execution of a precise set of actions. Unfortunately, those actions are not always in the best interest of the members in the supply chain, i.e., the supply chain members are primarily concerned with optimizing their own objectives, and that self serving focus often results in poor performance. However, optimal performance is achievable if the firms coordinate by contracting on a set of transfer payments such that each firm's objective becomes aligned with the supply chain's objective.(p.2)

The recent supply chain literature reviewed for this study highlighted the growing research interest in transshipments. Although a variety of research opinions were presented a common theme was the recognition that under specified circumstances, the use of transshipments could reduce inventory levels while maintaining required customer service. Chiou (2008) examined how transshipment originated from the concept of risk-pooling between the stock-keeping locations. He found that a considerable amount of research had been dedicated to transshipment and proposed several distinct features that should be taken into account when trying to optimize supply chains. Chiou framed his research by proposing the basic questions of when to replenish and how much stock to replenish. He also proposed three possible activities if transshipment was permitted: (a) demand was met from the stock on-hand, (b) demand was met via transshipment from another location in the system, or (c) demand was backordered.

The observations proposed by Chiou (2008) were similar to a news vendor problem of the type offered by Bell (2001). Chiou reasoned that if a location's on-hand inventory level was greater than the demand size, the demand was met. He argued that when the on-hand inventory level was positive but less than the demand size, the inventory should be used to partially satisfy the demand and the remaining demand should be met through transshipment or backorder. In the case where the on-hand inventory level was zero, the demand should be met via transshipment or be backordered. When Chiou's research was contasted with Holsenback and McGill (2007) a failing to consider how the costs of excess inventory levels affect profit was evident. Chiou's findings could be compared to those of Bell (2001) and Porteus (2002) who argued that the optimum inventory level should be based on the probability of a stockout being set equal to the ratio of the inventory item's unit cost to its unit price.

Tagaras (1989) determined that because transshipments have been the subject of a great deal of research they are generally seen as having the ability to provide an effective mechanism for correcting discrepancies between the locations' observed demand and their available inventory. His research showed that participation in transshipments could lead to cost reductions and improved service without necessarily increasing system-wide inventories. Tagaras' research did not specifically address the occurrence of random demand but instead focused on known historical demand. To his credit, Tagaras was one of the first supply chain researchers to study a two retailer mode and determine that if the total reserved inventory for the two retailers was pooled and used to replenish both of the retailers from a central location service levels at both of the retailers would increase. Several years later Ballou and Burnetas (2003) similarly examined the concept of transshipment by comparing traditional inventory planning approaches to an approach that used inventory at multiple locations as a backup inventory stock to achieve high customer fill rates. They evaluated the pull-type inventory system featuring stocking levels based on demand, costs, and customer service requirements linked to a specific geographic region on the ability to achieve lower inventory levels than a push-type system.

Ballou and Burnetas (2003) also researched the practice of companies incorporating transshipment policies to counter the occurrence of stockouts resulting from the effect of customer fill rate policies set at levels less than 100%. They found transshipments to be an effective method of reducing safety stock levels while maintaining high customer fill rates. They concluded that when fill rates were less than 100%, transshipments created a more balanced demand situation throughout the system. Their research results also showed that fill rates and differences in demand at supply points directly affected inventory levels, the greater the demand imbalance, the greater the requirements for inventory. Conversely, they found that the creation of balanced demand among dispersed supply points created a condition of maximum inventory.

A shortcoming of the approach taken by Ballou and Burnetas (2003) was their failure to consider the case where no demand history for a product existed and demand was stochastic. The authors based their analysis on the simplifying assumption that initial demand forecast were possible because of the existence of historical data. Holsenback and McGill (2007) provided an expanded approach from that of Ballou and

Burnetas by advocating the importance of understanding the statistical nature of demand to determine proper inventory levels. The authors examined statistical methods used to determine variability between actual and forecasted demand based on a three-level stratification scheme. They concluded that service levels should be assigned to stock based on the demand variance instead of cost and that unnecessarily high service levels resulted in excess inventory and increased carrying costs.

Several authors favored the use of mathematical procedures to develop technical rules for managing inventory and cost. A number of these approaches offered well-defined mathematical methods for modeling inventory but tended to be limited in application due to the specific defined environments they were developed to model. Cohn and Barnhart (2006) assessed the value of employing heuristics to solve the problem of how to stock both high cost and low demand repair parts while Wong, Van Houtum, Cattrysse, and Van Oudheusden (2005) presented a number of lemmas to prove the effectiveness of heuristics for use in estimating total inventory costs. Axsater (2003) reported on his use of the Poisson probability distribution to research single-echelon inventory systems composed of parallel local warehouses facing random demand. A common aspect of these models was that they all utilized probability distributions to estimate a quantifiable demand during a specified time period and neglect the occurrence of random demand.

It was interesting to consider the simplifying assumptions employed by Axsater (2003) who based his analysis on the assumption of standard holding, backordering, and ordering costs at all warehouses under investigation. He employed the use of lateral transshipment where performance results were calculated on the assumption that they take no time but incur additional costs. Axsater also presented a decision rule which assumed complete and up-to-date information on the inventory system. One unique element of his approach was the decision not to consider holding costs during transportation from the supplier to the warehouse, but to account for these costs by adjusting transshipment costs. Axsater simplified his problem analysis by assuming that once transshipment had occurred there would be no further transshipments made, allowing the expected costs to be minimized under this assumption.

Dong and Rudi (2004) proposed transshipment as a mechanism to better match supply and demand for the specific case where supply lead time was long and demand at each supply point was difficult to predict. The authors proposed that transshipment should be viewed as a special form of risk pooling that used pooled resources to satisfy several classes of demand. To validate their approach they employed a single period model using a simplifying assumption that retailers had identical cost and revenue parameters. The authors compared inventory levels under no transshipment to inventory levels under transshipment to analyze their effect on order quantities and profit. Unlike Axsater (2003), Dong and Rudi added to the realism of supply chain activity by incorporating the additional element of considering salvage value for left over inventory and the special case of costless transshipment.

A common theme among the research following a mathematical approach was the use of simplifying assumptions developed to increase the tractability of the inventory problem being examined. Zhang (2005) extended the results of Dong and Rudi (2004) to general demand distributions by applying the simplifying assumption that an inventory problem with transshipment was equivalent to a newsvendor problem with adjusted demand. Inventory control with lateral transshipments received a good deal of attention from Rudi et al. (2001) who studied a two-echelon inventory system with transshipment and presented models for inter-firm and intra-firm transshipments. They concluded from their research that the optimal inventory orders increased with transshipment prices and optimal inventory order choices for individual supply points did not necessarily maximize system profit.

Grahovac and Chakravarty (2001) used a much simpler decision rule than the ones proposed by Cohn and Barnhart (2006) and Wong et al. (2005). Grahovac and Chakravarty's simple decision rule for lateral transshipments was based on specified inventory which served as triggering points to effect transshipments. The triggering points served as predetermined inventory order points that could be adjusted for future estimated demand based on historical demand. Grahovac and Chakravarty examined the effects of transshipments while focusing on expensive, low demand items using one-for-one control policies in a vertically integrated supply chain.

Their research highlighted the difficulties of maintaining good customer service levels while minimizing inventory holding costs. Qin (2005) also considered customer service levels and inventory holding costs. He proposed a unique approach for viewing transshipments by comparing the benefits of virtual transshipments to real transshipments to analyze the effects of unit holding cost, production cost, and customer service levels. Qin employed a computational methodology to compute expected cost savings compared to the no-transshipment case.

Zanoni et al. (2005) took a similar approach to that of Grahovac and Chakravarty (2001) by examining the availability requirements for high value repair parts for complex technical systems such as jet aircraft engines in a two-echelon supply system. They determined that for expensive systems such as aircraft, ships, and computer systems high fill rates were required by customers as an insurance against excessive downtime. They also examined the outcome of reducing the number of echelons in the supply chain to reduce costs. Similarly, Chou et al. (2006) developed an analytical framework for studying a two-echelon distribution system with transshipments to assess the affect of transshipments on reducing cost of the distribution system.

Several papers to include those of Axsater (1990, 2003), Grahovac and Chakravarty (2001), and Rudi et al. (2001), Wong et al. (2005) presented heuristic decision rules for lateral transshipment and evaluated the optimal replenishment policy under these decision rules. The authors had a common goal of expanding the then existing research by examining centralized decision-making and the use of incentives to foster participation in transshipments between independent supply points. Rudi et al. expanded the research by studying a two-location model with decentralized decision-making compared to a single echelon model and argued that increasing the number of echelons allowed them to more closely model supply chain operations.

Dong and Rudi (2004) applied economic theory to analyze how transshipment could benefit a manufacturer and multiple retailers in settings where the manufacturer could serve as a price setter or a price taker. In their model, the multiple retailers had the same cost structure and complete pooling among retailers was assumed. Zhang (2005) achieved similar results by extending Dong and Rudi's results to general demand distributions by relaxing model constraints and allowing for suboptimal results.

Several researchers used modeling and simulation of supply chain inventory to study the relationships between inventory cost and profit. Himden et al. (2007) employed simulation to study transshipment policy with the aim of reducing inventory costs and improving customer fill rates. They developed a multi-agent transshipment model for simulating the cooperated behavior of inventory locations that incorporated the parameters of non-negligible transshipment lead times and limited transportation mean capacity. Himden et al. determined that transshipment was an effective inventory collaboration method that could achieve inventory cost reductions.

Unlike the majority of the research which employed the simplifying assumption of similar cost structures for supply points within a specified system, Himden et al. (2007) considered the more realistic case of supply points having non-identical cost structures. They incorporated the use of interface and location agents to negotiate transshipments and facilitate cooperation among supply points to reduce total inventory cost and to improve customer fill rates. Their cooperation and collaboration experimentation was similar to the economic approach used by Dong and Rudi (2004) in which the manufacturer could serve as a price setter or a price taker. Himden et al. examined the case where cooperative inventory management existed among supply points without the need for transshipment incentives and concluded that transshipments were an effective tool for managing inventory levels.

Chiou (2008), and Saetta, and Tiacci (2003) utilized modeling and simulation to demonstrate the use of transshipments to realign inventory balances among supply points. Saetta and Tiacci were some of the few researchers to introduce the concept of a negotiation mechanism between agents to facilitate participation in transshipments and avoid the costly urgent resupply shipment from a central warehouse. Qin (2005) examined the effectiveness of revenue-sharing contracts as a means of promoting cooperation between the supplier and supply points belonging to the same firm and facing stochastic demand. Qin extended the analysis of inventory levels to include the provision for salvage value for unsold inventory under two conditions: (a) salvage revenue was shared by those elements participating in transshipments, and (b) salvage revenue was not shared but kept by the inventory holder.

Ozdemir, Yucesan, and Herer (2006) researched coordination among stocking locations through replenishment strategies that explicitly took into account lateral transshipments of a product among locations at the same echelon level. They used a strict mathematical approach and formulated the capacitated production case as a network flow problem embedded in a stochastic optimization problem and developed a solution procedure to solve the problem numerically. The authors concluded that either capacity or transshipment flexibility was required to maintain a certain level of service. One concern this researcher had with the mathematical approach was the generally used assumption that perfect knowledge of the inventory was available. In reality perfect information is seldom achieved.

Benjaafar, Cooper, and Kim (2005) studied pooling of inventories in a supply chain with symmetric costs where demand arrived dynamically and supply lead times were endogenous and generated by a production system with finite capacity and stochastic production times. The authors noted that while inventory pooling had been an important theme in the operations management literature it had largely focused on the analysis of single period problems or problems with multiple periods but with exogenous lead times. They argued that the need to consider pooling arose in industries where production and inventory were tightly coupled. The authors envisioned that the models they presented would be used by firms to support strategic decisions about when and how to pool inventory.

Benjaafar et al. (2005) found from their research that the percentage cost reduction from inventory pooling should be expected to decrease with utilization once utilization reached a sufficiently high level. In heavily loaded systems, the percentage cost reduction becomes insignificant and a pooled system offered no relative advantage to a distributed one. These results disagreed with the results of Chiou (2008), Dong and Rudi (2004), Grahovac and Chakravarty (2001), Himden et al. (2007), Rudi et al. (2001), and Saetta, and Tiacci (2003) who generally agreed that pooled inventory offered cost advantages by reducing inventory levels.

Benjaafar et al. (2005) further concluded that the absolute cost savings from pooling could be smaller and even go to zero if the distributed system was managed more effectively. Although total cost was reduced when inventory was pooled, the performance of individual customer classes could deteriorate. By examining inventory pooling in production-inventory systems the authors showed that the utilization, demand and process variability, control policy, service levels, and the structure of the production process all played a role in determining the value of inventory pooling.

Summary. The literature presented in this section represented the great deal of research that has focused on transshipments in recent years. The majority of the research conclusions contained in the literature presented transshipment as an effective mechanism for correcting discrepancies between a locations' observed demand and the available inventory and as an effective method of reducing safety stock levels while maintaining high customer fill rates. Several authors proposed transshipment as a mechanism to match supply and demand when demand was difficult to predict. Several authors also proposed that transshipment should be viewed as a special form of risk pooling that used pooled resources to satisfy several classes of demand. In this section, analytical techniques for assessing the effectiveness of transshipments were discussed to include the use of simplifying assumptions to improve the tractability of inventory problems.

The use of simulation to study transshipment policy was presented using models for simulating the cooperated behavior of inventory locations and for demonstrating the use of transshipments to realign inventory balances among supply points are presented. The concept of a negotiation mechanism between agents to facilitate participation in transshipments and avoid the costs associated with urgent resupply shipments from a central warehouse was briefly introduced along with the practice of revenue-sharing contracts between the supplier and supply points belonging to the same firm and facing stochastic demand. The effect of random or stochastic demand was introduced and its effects on the pooling of inventories in a system with inventory costs and supply lead times were assessed.

Incentives for Transshipment

The effectiveness of inventory sharing in supply chain partnerships was investigated and analyzed by Gunasekarana et al. (2004) who observed that the discrete sites in a supply chain did not maximize efficiency if each pursued goals independently. The authors argued that supply chain partnership could best be described as a collaborative relationship between a buyer and seller who recognized some degree of interdependence and cooperation. Zhao, Deshpande, and Ryan (2005) similarly studied the lateral sharing of inventory from the perspective of depots, dealers, and retailers and concluded that the main advantages of inventory sharing among these entities included reduced inventory levels and generally higher system service levels. They also found that the main drawbacks associated with inventory sharing included increased transportation, handling, and administration costs.

Fu and Piplani (2004) provided a view of supply chains very different from those described by Gunasekarana et al. (2004) and Zhao et al. (2005). Fu and Piplani described a supply chain as a sequence of weakly connected activities and decisions both within and outside of the organization. They noted that while a lack of cohesion destroyed value in the supply chain collaboration created value opportunity which could drive effective supply chain management. They further argued that to be effective, collaboration mechanisms must be able to influence the decisions in supply chains.

Cachon (2003) studied the effectiveness of revenue sharing contracts in a general supply chain model with revenues determined by each retailer's purchase quantity and price. Under a revenue sharing contract, a retailer pays a supplier a wholesale price for each unit purchased, plus a percentage of the revenue the retailer generates. Cachon took an approach similar to that of Fu and Piplani (2004) and chose to explore the use of revenue sharing to coordinate a supply chain with a single retailer that chooses optimal price and quantity and arbitrarily allocated the supply chain's profit. Unlike Cachon, Fu and Piplani identified several limitations of revenue sharing that could be used to explain why revenue sharing was not prevalent in all industries. Their research showed how revenue sharing could alter the performance of a supply chain and suggested that the amount of variability in supply chain demand affected the revenue sharing performance and high levels of variability may not justify the cost of revenue sharing's administrative burden.

Simatupang and Sridharan (2002) conducted research on collaborative supply chain partnerships in different companies and arrived at one conclusion that partially contradicted the findings of several researchers (Cachon, 2003; Fu & Piplani, 2004; Gunasekarana et al., 2004; Zhao et al., 2005). Simatupang and Sridharan concluded that although partnership promises mutual benefits, they were rarely realized due to lack of information sharing and a tendency to local optimization which contributed to lower overall performance of the chain. The authors argued that concern for profit from a local perspective coupled with the opportunistic behavior caused a mismatch between supply and demand.

Simatupang and Sridharan (2002) argued that this supply and demand mismatch could play a role in accounting for stockout costs, markdowns, expediting, transshipment, advertising and sale preparation costs, excess inventory costs, obsolescence, and disposal costs. The authors concluded that a supply chain which limited itself to local measures of performance could not perform as an integrated link. In their view, individually held policies too often contributed to cost ineffectiveness, poor customer service, and lower profitability of the overall chain. The authors advised that although collaboration was based on a mutual objective, collaboration was a self-interested process as each member sought to achieve individual benefits such as eliminating redundant functions, reducing transactions, achieving lower inventory, and increasing responsiveness.

The collaborative supply chain research conclusions (Cachon, 2003; Fu & Piplani, 2004; Gunasekarana et al., 2004; Zhao et al., 2005) generally agreed that a supply chain could benefit from joint initiatives that ensured that each partner had a stake in success. The research into collaborative supply chains provided results that indicated incentives to collaborate were effective if they were delivered in a timely manner. The results also supported the conclusion that incentives should be fair and equitable so that the participating parties jointly agreed on a single set of performance measures and on a gain sharing formula universally perceived as equitable in determining the fair distribution of gains. Simatupang and Sridharan (2002) concluded that any action directed at improving individual performance without appreciation for improving customer service at reduced overall costs, was likely to have a detrimental effect on at least one or more chain partners.

Zhao et al. (2005) reported on a comprehensive review of a number of inventory sharing programs including Caterpillar, John Deere, and General Motors where participating dealers were allowed to adjust the values of the parameters that indicated which parts they wanted to share and the amount of sharing desired for each part. The authors identified several key managerial issues encountered in decentralized dealer inventory sharing systems to include: (a) optimal inventory replenishment and sharing policies for the individual dealers, (b) inventory sharing strategies, and (c) incentives for the manufacturer to offer to the dealers in order to promote dealer inventory sharing. Zhao et al. developed a framework for modeling and analyzing inventory sharing problems in decentralized dealer networks that was similar to the one proposed by Cachon (2003). Their research conclusions stood out because they highlighted the author's opinion that because the management of a service parts supply chain was especially challenging when dealing with low-demand rates, expensive parts and high service requirements an increasing number of manufacturers have begun pursuing a strategy that promotes inventory sharing among the dealers in their distribution network.

Zhao et al. (2005) were strong advocates of the importance of customer service and argued that the importance of customer service had driven firms to place more emphasis on supply chain management. The author's method and approach for modeling the influence of customer service was interesting because of the framework it presented for analyzing inventory sharing problems in decentralized dealer networks using dynamic programming to characterize the structure of the optimal policy for an individual dealer. A shortfall in this approach was that the authors chose to characterize the performance measures for the sharing policy by employing known demand estimates in a set time period. It is this researcher's opinion that greater insight into the influence of customer service on supply chain dynamics could be achieved by expanding the research to also account for the effects of random customer demand for a product. An expanded treatment considering random demand, similar to that proposed by Porteus (2002) would provide a more realistic model of supply chain activity.

Zhao et al. (2005) also researched inventory-sharing strategies that encouraged dealers to share their excess inventory with other dealers. The authors found that inventory pooling allowed the dealers to respond to demand by sharing inventory in return for a pre-specified commission. They also found that inventory pooling alleviated the dealers' burden of maintaining inventory stocks and provided access to parts stocked by other dealers. The authors presented several key findings from their research that were applicable to the research method used in this dissertation: (a) incentives for the sharing of inventory could have a direct impact on the level of inventory sharing engaged in by the independent dealers, (b) a small level of incentive for inventory sharing may be sufficient to achieve the benefits of a full-inventory sharing policy, (c) the benefit of inventory sharing increased as the system utilization increased, and (d) customer service may improve significantly with inventory sharing.

Ziya (2004) studied the relationships between independent supply points and their suppliers and concluded that the misalignment of interests between the independent supply points and suppliers was a common occurrence. He theorized that suppliers wanted the supply points to carry as much stock as possible but that they had incentive to under-stock and prefered to pool inventory across the supply points. Ziya argued that the research was lacking because inventory pooling or transshipment of stocks had mostly been analyzed in a single echelon setting. In this dissertation a two-echelon setting was considered to model the interactions among the supply points and assess the utility of a profit-sharing incentive as a way of coordinating the supply chain. This researcher believed that Ziya's approach was applicable to this study because of its focus on optimizing the inventory management policies for the supply chain as a whole and at the same time giving adequate incentives to all the players so that they would participate in the optimal inventory management policy.

Summary. This section presented a review of research that focused on the lateral sharing of inventory among depots, dealers, and retailers and the ability of inventory sharing to reduce inventory levels and provide higher system service levels. The research reviewed for this dissertation provided results indicating that revenue sharing altered the performance of a supply chain and suggested that the amount of variability in supply chain demand affected the revenue-sharing performance and high levels of variability may not justify the cost of revenue sharing's administrative burden. A brief review of collaborative supply chain partnerships was presented that assessed the ability of companies that shared inventory to match demand with supply more effectively than companies could alone. Research was also presented that contradicted the benefits of inventory sharing and argued that although partnerships promised mutual benefits, they were rarely realized due to lack of information sharing and a tendency toward local optimization which contributed to lower overall performance of the supply chain.

The literature reviewed generally indicated that a collaborative supply chain could benefit from joint initiatives to ensure that each partner had a stake in success. Furthermore, it was suggested that incentives to collaborate could only be effective if they were delivered in a timely manner. Several researchers argued that the incentive should also be fair and equitable and that incentives were found to be most effective when the participating parties jointly agreeded on a single set of performance measures, using gain sharing formulas perceived as equitable in determining the fair distribution of gains. Inventory sharing strategies that encouraged dealers to share their excess inventory with other dealers were highlighted which indicated that inventory pooling could alleviate the need to maintain high inventory levels.

Mathematical Modeling and Simulation of the Supply Chain

The use of modeling and simulation as a means for understanding issues of supply chain operations has gained importance in recent years (Ballou & Burnetas, 2003; Chase et al., 2006, Winston, 2004). Swaminathan, Smith, and Sadeh (1998) used modeling to effectively evaluate various policies for demand, supply, information, and materials control within a supply chain. The authors used a combination of analytical and simulation models to study both the static and dynamic aspects of supply chain problems. The authors found it difficult to develop a set of generic processes that captured the dynamics of supply chains across a wide spectrum due to the presence of multiple performance measures and complex interaction effects. They concluded that simplifying assumptions are often required to reduce the supply chain complexity to a manageable level.

Several authors employed supply chain simulation as a key component and methodology in their research. Swaminathan et al. (1998) focused their research to address methods for controlling the inventory within the supply chain while providing the required service to customers. They were early proponents of simulation and argued that due to the difficulty of creating tractable analytical models for dynamic supply chain problems under realistic assumptions simulation was an effective method to analyze these types of problems. The authors favored the development of models requiring minimum programming effort that made use of higher-level modeling primitives to encapsulate building blocks for supply chain models. The authors advocated that due to the simplistic approach their research framework it could be utilized directly by supply chain managers who were faced with specific configuration, contracting, or coordination issues.

Disney et al. (2006) advocated that modeling and simulation could be used to represent the relationships which described the dynamics of inventory in supply systems. The authors used simulation to model a system's inventory replenishment order to its inventory demand process, defined as the ratio of the output variable to the input variable.

They researched the development of transfer functions to address standard linear replenishment rules by modeling time in integer multiples of a planning period in a generic single echelon of a supply chain. Kang and Gershwin (2005) applied probability distributions in a similar manner to model and measured the effect that the rate of stock loss could have on the inventory and replenishment process. For their simulation model, they applied a Poisson distribution for stock loss and the supply chain demand during each period which was assumed to be independent and normally distributed with known and fixed lead times. Using a probabilistic modeling approach, Kang and Gershwin arrived at conclusions similar to Ballou and Burnetas (2003), Blanchard (2004), Holsenback and McGill (2007), and Qin (2005) regarding the importance of stockouts and their negative impact on customer service.

One theme repeated in the reviewed literature was the use of simplifying assumptions by the researches that treated the demand for purchase and stock loss as constant and continuous vice using stochastic demand. By developing a model with deterministic demand and stock loss, the authors were able to simplify the role that randomness played in the inventory inaccuracy problem. The close agreement of the deterministic model calculation and their simulation results led the authors to conclude that system performance was highly sensitive to the inventory inaccuracy created by stock loss. They concluded that for systems operating in lean environments, inventory accuracy and performance was a critical management function.

Liu et al. (2004) followed an approach similar to that of Swaminathan et al. (1998) by studying the issue in supply chains of simultaneously controlling inventory costs at different locations throughout the system while satisfying customer service-level requirements. The authors set out to define and solve a nonlinear constrained optimization problem that captured the key dynamics of a complex production-inventory system. They developed their multistage inventory model to evaluate the performance of serial manufacturing and supply systems with inventory control in order to minimize the overall inventory in the system while meeting the required service level.

Liu et al. (2004) favored a probabilistic approach over the deterministic approach favored by Gupta and Maranas (2003) and Kang and Gershwin (2005). They argued that their procedure was relatively simple and delivered accurate performance estimates. Liu et al. also developed an approach to deal with complex supply network design problems by modeling the interactions of the queuing and inventory stocking in a network setting. They hoped to expand the boundaries of supply chain design methodology by proposing a queuing model for a serial supply system that incorporated an inventory control mechanism. Their model used a simple approach to decompose the performance of a multistage system into multiple single stage inventory queues, each with a modified material arrival process. This novel approach enabled them to solve an optimization problem that minimized the total inventory cost subject to a required service level.

The deterministic planning models prefered by Gupta and Maranas (2003) were aimed at determining the optimal sourcing and allocation of limited resources to satisfy the market demands in the most cost-effective way. To accomplish this, they considered a supply chain network consisting of multiple production sites, manufacturing multiple products assuming a planning horizon of from one to two years. Each production site was characterized by one or more semi-continuous processing units having limited capacity. The benefit of this approach when compared to that of Kang and Gershwin (2005) was that the objective function of the deterministic model captured the combined costs incurred in the manufacturing and logistics phases and helped to account for uncertainty in the planning decisions.

In the approach used by Gupta and Maranas (2003) uncertainty was described by a set of discrete scenarios capturing how the uncertainty might affect future outcomes. Each scenario was associated with a probability level representing the decision maker's expectation of the occurrence of a particular scenario. The approach modeled the demand as normally distributed with a specified mean and standard deviation. The presence of uncertainty was reflected by the fact that both the decisions as well as the costs were probabilistic.

Operating under the premise that cost-effective supply chain management under uncertainty was a critical issue for companies, Jung, Blau, Pekny, Reklaitis, and Eversdyk (2004) researched the use of inventory levels to hedge against demand uncertainty in supply chain operations and design. The authors found that uncertainties in the supply chain increased the variance of profits or costs to the company and that demand uncertainty was an important factor to be considered in the supply chain design and operations. The authors proposed the use of planning and scheduling models incorporating inventory stock levels as a means of accommodating demand uncertainties and to meet a desired level of customer satisfaction.

The importance of customer satisfaction and its linkage to inventory cost was evident in the model proposed by Jung et al. (2004). They used expected values of future demands and incorporated inventory stock levels for each product and site within the supply chain. The authors, along with Zabawa and Mielczarek (2007), were the only researchers identified in the literature review that used simulated demand generated by a Monte Carlo process. The authors generated simulated demand data in order to determine the customer satisfaction level extending over a defined planning horizon. These multiple simulations provided an estimate of the customer satisfaction level achieved under specified cost and demand parameters. The author's unique approach had shortcomings in that the decomposition strategy used could only provide suboptimal solutions which required increased computing times to address problems of increasing scope.

Santoso et al. (2005) researched a large number of optimization-based modeling approaches that had been proposed for the design of supply chain networks. They found in their review of literature that while the critical parameters such as demand, prices and resource capacity were uncertain, the majority of the approaches assumed that the operational characteristics of the supply chain were deterministic. The authors chose to develop an algorithmic strategy for modeling large-scale supply chain network design problems under uncertainty. They argued that their proposed methodology provided an efficient framework for identifying and statistically testing a variety of candidate design solutions that incorporated random demand. The preponderance of supply chain literature reviewed for this study assumed that transshipments within an echelon offered a capability for reducing inventory levels and cost while maintaining customer service levels.

A number of studies using simulation models that employed transshipments were reviewed in the literature typically assumed very simple transshipment policies that did not take into account random demand and inventory reservation levels below which a supply point may not be willing to participate in transshipments. Chiou (2008) employed a simulation model to evaluate the effectiveness of three different transshipment rules and two inventory control policies. His simulation experiments were designed to demonstrate the benefits of using transshipment, and to compare the performance of the different inventory policies and transshipment rules. Chiou employed a distribution system consisting of two geographically dispersed distribution centers compared to the single distribution point proposed in this dissertation. Chiou described the operating conditions in his study by using selected statistical factors such as the mean of demand and the coefficient of variance of demand degree which is equal to the average divided by the standard deviation.

The research results from Chiou (2008) indicated that when transshipments were allowed at both levels of distributors and retailers the benefits of transshipment appeared to be significant. His study extended several previous research efforts (Disney et al., 2006; Kang, & Gershwin, 2005; Liu et al., 2004; Swaminathan et al., 1998) by incorporating a combination of transshipment and inventory control policies along with cost considerations into the analysis. His main finding was that using lateral transshipment in cooperation with inventory policies could result in lower cost under a given service level. He determined that transshipments had the potential to reduce costs and improve inventory availability.

Zabawa and Mielczarek (2007) described the modeling of supply chains using Monte Carlo simulation to find the minimal inventory cost. Their research evaluated the quality of implementation of inventory control policies according to total inventory cost over a specified time. The authors defined total inventory cost along the same lines as did Holsenback and McGill (2007) with the main cost components being composed of holding costs, ordering cost and stockout cost.

The study by Zabawa and Mielczarek was one of the few reviewed that rejected the assumption of demand being known or constant in their models. They argued that the size of inventory stock should be based on stockout and maintenance costs along with ordering and storage costs. The authors presented a unique approach incorporating a business game which simulated a pull system to model goods demanded and the time required to fulfill an order by the supplier. The authors advocated using simulation runs to test various schemes of order quantities and reorder points and to minimize the total inventory cost.

Perng and Ho (2007) used a business game approach similar to the one proposed by Zabawa and Mielczarek (2007) to simulate the operation of a transshipment center using four scenarios depicting the transport of goods. Using these four scenarios, Perng and Ho created an extra supply chain cost equation to validate the results and provide empirical data to simulate the research problem. The authors conclude that the larger the transshipment center, the lower the extra cost. They also concluded that extra cost would be minimized if the transshipment center returned the superfluous goods directly because of high space and reorganization cost.

Perng and Ho (2007) further argued that the transshipment center problem was important in supply chain management because most of the relevant existing research focused on networking, and did not consider the dynamics of the configurations in transshipment center units. The authors researched the use of polynomial-time algorithms to model integral optimum flow and went on to formulate the warehouse storage capacity problem as a nonlinear programming model to minimize the total cost in supply chains operating under uncertainty.

Summary. The literature presented in this section provided insight into the use of modeling and simulation to represent inventory in supply chain operations. The literature revealed a range of opinions on various approaches to modeling. The reviewed research highlighted the important issue in supply chain management of controlling inventory costs at different locations throughout the system while satisfying customer service-level requirements. One recurring theme in the literature was that modeling and simulation were shown to be useful tools that could be used to relate a system's inventory replenishment order to its inventory demand process. A number of the research approaches employed assumptions to simplify the complex mathematics involved in modeling supply chain operations.

Inventory models incorporating simplifying assumptions were commonly used to determine the optimal sourcing and allocation of limited resources to satisfy the market demands in the most cost-effective way. The studies presented in this section used a combination of analytical and simulation models to study both the static and dynamic aspects of supply chain problems. The presented research was focused on controlling the inventory within the supply chain while providing the required service to customers. The research indicated that uncertainties in the supply chain could increase the variance of profits and costs and that demand uncertainty was an important factor to be considered in the supply chain design and operations.

General Summary

In the past half century, the field of supply chain management has experienced significant change and development and taken on greater importance as nations attempted to rebuild their industrial capacity that had been destroyed during World War II. Cartiledge (2004) and Chase and Aquilano (1992) discussed how during the 1950s the field of supply chain management was developed to enable manufacturing companies to increase their competitiveness and their market share and profitability. In the 1960s inventory management software systems such as MRP were developed to aid inventory control in the manufacturing sector (Chase & Aquilano, 1992). By the 1980s MRP II was developed for planning all manufacturing resources with a new emphasis being placed on increasing productivity and decreasing cost by actively managing inventory levels.

In the 1990s advances in computer technology led to the development of ERP, which took advantage of the developing information technology architecture which made it feasible to integrate the business applications of a corporation with a common data base (Chase & Aquilano, 1992). From the 1990s to the present advances in high-speed computers and network systems have supported the development of lean production philosophy and the concepts of JIT and TQC to manage inventory. In this environment inventory has taken on increased importance as a key cost element in the supply chain.

Advancements in information technology placed greater emphasis on speed of knowledge to meet customer service requirements. Zanoni et al. (2005) observed that the importance of inventory management increased in the past decade because of the systems availability and high quality after sales service demanded by customers. Authors such as

Qin (2005) concentrated their research on managing inventory under uncertain demand. The important role that inventory plays in cost was studied by several authors. Holsenback and McGill (2007) advocated that inventory holding cost and safety stock inventory are critical to the effective management of inventory. They argued that few managers know the true value of inventory holding cost, and that few realize the true affect that on inventory management decisions have on profit.

Chiou (2008) studied the concept of risk-pooling between the stock-keeping locations. The practice of transshipments was studied by authors such as Tagaras (1989) who determined that transshipments were generally seen as having the ability to provide an effective mechanism for correcting discrepancies between the locations' observed demand and their available inventory. Ballou and Burnetas (2003) found transshipments to be an effective method of reducing safety stock levels while maintaining high customer fill rates. They concluded that when fill rates were less than 100%, transshipments created a more balanced demand situation throughout the system.

Advancements in computers and information systems also greatly facilitated the mathematical analysis of supply chain operations as seen in the research by Axsater (2003), Cohn and Barnhart (2006), Dong and Rudi (2004), and Wong et al. (2005). These researchers assessed the value of employing mathematical models to solve several problems to include: how to stock high-cost and low-demand repair parts, how to use mathematical models to estimate total inventory costs, and how to use mathematical decision rules based on complete and up-to-date information on the inventory system to better match supply and demand when supply lead time is long and demand at each supply point is difficult to predict.

The application of mathematical analysis and modeling techniques supported new research on the use of transshipments. Zhang (2005) extended the results of Dong and Rudi (2004) by demonstrating that an inventory problem with transshipment was equivalent to a newsvendor problem with adjusted demand. Axsater (1990, 2003), and Grahovac and Chakravarty (2001) expanded the research on transshipments by examining centralized decision-making and the use of incentives to foster participation in transshipments between independent supply points.

The development of effective simulation techniques also significantly facilitated supply chain analysis. Himden et al. (2007) employed simulation to study transshipment policy with the aim of reducing inventory costs and improving customer fill rates. Unlike the majority of the research which assumed similar cost structures for supply points within a specified system, they considered supply points having non-identical cost structures. Chiou (2008), and Saetta and Tiacci (2003) employed modeling and simulation to demonstrate the use of transshipments to realign inventory balances among supply points.

Saetta and Tiacci (2003), and Qin (2005) introduced the concept of using incentives to facilitate participation in transshipments. Several researchers conducted simulations based research focused on supply chain collaboration to include Gunasekarana et al. (2004), Simatupang and Sridharan (2002), and Zhao et al. (2005). Their research on collaborative supply chain partnerships provided a framework for modeling and analyzing inventory sharing problems in decentralized dealer networks. The authors found that inventory pooling provided a means to respond to unforeseen demand and lower inventory stocking levels while maintaining specified levels of customer service. Disney et al. (2006) and Gupta and Maranas (2003) advocated that modeling and simulation could be used to represent the relationship describing the dynamics of inventory in supply systems.

The authors used modeling and simulation to determine the optimal sourcing and allocation of limited resources to satisfy the market demands. Gupta and Maranas (2003) and Kang and Gershwin (2005) applied separate mathematical distributions to model and measure the effect that the rate of stock loss could have on the inventory and replenishment process. They advocated the effectiveness of employing deterministic planning models aimed at identifying the optimal sourcing and allocation of limited resources to satisfy the market demands in the most cost-effective way.

Dealing with demand uncertainty and managing inventory levels was an important element of supply chain management that has been the subject of considerable research. The literature reviewed for this research included results that indicated transshipment could be an effective means of reducing inventory levels and costs while maintaining high customer service levels under specified assumptions. Transshipment studies were common and studies in the literature typically assumed simple transshipment policies based on periodic review and replenishment in a centrally controlled supply chain. A weakness of these studies is that they did not take into account the combined effects of random demand, required levels of customer service, and inventory reservation levels below which an independent supply point might not be willing to transship or the amount of incentive needed for the supply point to participate in the transshipments. These simplifying assumptions also often disregarded the effect of future stochastic demand occurring.

Transshipment was generally considered to be an effective means of reducing inventory levels and costs while maintaining high customer service levels. From the literature review it became evident that transshipment was generally thought to facilitate the use of available inventory to solve system-wide demand. However, the preponderance of research ignored the complex components of transshipments by assuming: immediate availability, no replenishment lead-time, and no loss of customer goodwill. Shortfalls in this research include a concentration on demand and inventory levels at time of demand while failing to consider subsequent demand after transshipments have occurred.

Chapter 3: Research Method

This quantitative experimental study addressed the problem that demand uncertainty and the amount of inventory held by a business directly affects that business's ability to maximize profit and meet required levels of customer service and availability. Excess inventory levels increased carrying costs while deficient inventory levels resulted in poor levels of customer service and lost sales. Demand uncertainty can make it difficult for a business to accurately determine the optimum inventory levels it should maintain. According to Holsenback and McGill (2007) inventory costs can represent one-third to one-half of a company's assets and account for a significant portion of the total cost of doing business. Inventory is necessary to insure customer satisfaction because the availability of the demanded product is often time-sensitive and requires a high degree of availability (Zanoni et al., 2005).

Due to the cost of holding inventory, business managers find it difficult to set planned inventory levels high enough to guarantee that 100% of the demand is satisfied from stock (Ballou & Burnetas, 2003; Holsenback & McGill, 2007; Huang et al., 2007). Demand uncertainty and the costs associated with holding inventory have a direct effect on a business's profit by tying up cash flow (Himden et al., 2007; Rudi et al., 2001). Several authors (Ballou & Burnetas, 2003; Holsenback & McGill, 2007; Himden et al., 2007; Huang et al., 2007; Rudi et al., 2001) have all noted the importance of developing and implementing effective inventory management policies that assist managers in minimizing inventory costs, meeting expected standards of customer service, dealing with random demand, and maximizing profit.

A review of literature revealed that transshipment was thought to be a cost effective method of dealing with demand, satisfying customer service levels, and reducing inventory levels. A shortcoming of the reviewed literature was that few transshipment studies considered the problem of random demand occurring at supply points after transshipment occured and the effect it had on system profit. The reviewed literature also did not address incentives that might be required to encourage the supply points to forego the potential risk of participating in transshipments.

The purpose of this quantitative experimental study was to assess the effect of transshipment on profit in a theoretical two-echelon supply chain. This study measured the ability of two proposed inventory management policies that were developed by the researcher, the standard and shared, to minimize cost and maximize profit. The standard inventory policy was designed for a setting where the supply points operate independently to maximize their individual profit. The shared inventory policy was designed for a setting where a central decision maker was responsible for coordinating participation in transshipments among independent supply points to maximize supply chain system profit.

The shared inventory policy employed monetary incentives to encourage participation in transshipments among the supply points. The risk of post transshipment demand was mathematically assessed and evaluated to determine how it impacted on profit under this inventory policy. In both the standard and shared inventory policies simulated inventory demand data was used to assess the inventory management policy's ability to minimize cost and maximize system profit. The system profit for the standard inventory policy served as a baseline measurement for comparison of the shared inventory policy system profit. In the shared policy, incentives were developed and used to encourage the independent supply points to participate in transshipments.

Research Questions

The study of inventory management provides businesses and managers with knowledge to implement effective inventory policy in supply chains. The knowledge of whether a specific inventory management policy is effective in minimizing cost and meeting required standards for customer service better helps managers and decision makers to maximize supply chain profit. Two goals of determining effective policy are to identify the true cost of inventory and to develop and employ measures that allow managers to make effective decisions regarding inventory levels that control costs. This study assessed the impact of transshipment on profit in a two-echelon supply chain by examining two proposed inventory management policies. The performance of the policies was evaluated in terms of inventory costs, customer service levels, and system profit by examining the following research questions and hypotheses which resulted in findings that may enable managers and decision makers to make informed decisions about the allocation of inventory levels to control cost and maximize profit.

Q1. Does an inventory management policy that uses transshipment achieve higher system profit than an inventory management policy that does not use transshipment?

Q2. Does the occurrence of random demand at a supply point after it has donated inventory for transshipment lead to decreased system profit?

Q3. Does the use of incentives to induce participation in transshipment lead to decreased system profit?

Hypotheses

The following are the null and alternate hypotheses that support the investigation of the research questions that are the focus of the study.

$H1_0$. There is no significant difference in total system profit when an inventory policy using transshipment is compared to an inventory policy that does not use transshipment.

$H1_a$. There is a significant difference in total system profit when an inventory policy using transshipment is compared to an inventory policy that does not use transshipment.

$H2_0$. There is no significant decrease in system profit when random demand occurs at a supply point after it has donated inventory for transshipment.

$H2_a$. There is a significant decrease in system profit when random demand occurs at a supply point after it has donated inventory for transshipment.

$H3_0$. There is no significant decrease in system profit when incentives are used to induce participation in transshipment.

$H3_a$. There is a significant decrease in system profit when incentives are used to induce participation in transshipment.

Research Methods and Designs

The key concept proposed in this quantitative experimental study was the formulation and use of inventory management policy models and simulation to assess the effect of transshipment on profit in a two-echelon supply chain. Mathematical modeling of a supply chain offers a scientific approach to decision making that seeks the best design and operation of a system requiring the allocation of scarce resources (Winston, 2004). Simulation is a technique that can be used to study a system and to gain insight into the relationships among various components, or to predict performance under some new condition (Sriudom, 2005). Mathematical models are often used to assist managers in planning and decision making and to evaluate competing alternatives based on performance (Ballou & Burnetas, 2003; Winston, 2004).

The two inventory management policies were used to model how transshipments among independent supply points affected profit and created verifiable cost and profit estimates. It was anticipated that these estimates would help managers to make confident, resource-saving decisions in two cases: (a) the first case was a setting where the supply points operated independently to maximize their individual profit and did not participate in transshipments, (b) the second case was a setting where a central decision maker was responsible for coordinating transshipments between independently operating supply points to meet customer demand and maximize supply chain system profit. Using simulated demand data as input for the inventory management policy models the resultant inventory levels, cost, and profit outcome for the two cases which were numerically compared and statistically analyzed to answer the research questions and hypotheses.

The proposed modeling and simulation methodology was chosen over other methodologies because it best supported the intent of mathematically assessing the impact of transshipment on profit. The intent of this study was achieved by using two proposed theoretical inventory management policy models to manage inventory, meet required customer service levels, address random demand uncertainty, minimize cost and maximize system profit. Because the proposed inventory management models were theoretical, there was no existing historical random demand data. The sample the needed to exercise the inventory policy models was simulated.

Chiou (2008), Winston (2004), Yi (2005), and Zhang (2005) discussed the validity of generating simulated random demand for specific periods. Winston (2004) argued that experimental data resulting from random assignments provided much stronger information about cause-and-effect relationships than observational data because randomization tends to balance out the effects of any other variables that might affect the dependent variable. The random demand sample needed to conduct this study was obtained using a pseudorandom integer generation algorithm defined in Equation 2. The sample size for the data set was determined using the Gaussian or Normal distribution.

The behavior and tractability of the Normal distribution made it appropriate to use when dealing with random samples (Winston, 2004). Validity of the simulated random demand was achieved by using statistical software developed by Arsham (2005) that tested for randomness to ensure the data elements were mutually independent and random using the Wald-Wolfowitz runs test. One of the strengths of the proposed methodology was the control over the independent variable that was exercised through random assignments. Because the modeling and simulation for the inventory policies required repetitive mathematical calculations, computer software programs were used to perform the required cost and profit calculations.

The advantages of this methodology were: the models were scalable and could handle simple to complex systems, once the model was built it could be used repeatedly to answer "what-if" questions, the models allowed study of interaction among variables, large time spans could be compressed for modeling purposes, and the models provided data for quantitative comparison of competing alternatives. The disadvantages of this methodology were: model building was time consuming, the models required limiting assumptions, models required mathematical sophistication, managers must choose solutions they want to try, and each model was unique and may require modification to address real world scenarios. In each of the proposed inventory policy models, the model calculations were performed on a Dell 630 computer using Excel spreadsheets and the MATLAB programming language.

Approach to Research. Axsater (2003), Ballou and Burnetas (2003), Chou et al. (2006), Grahovac and Chakravaty (2001), and Huang et al. (2006) determined that demand uncertainty and inventory costs were two key elements deciding what level of inventory was required to ensure specific levels of customer service and maximize profit. This quantitative experimental study employed two inventory management policies to assess the impact of transshipments on profit in a two-echelon supply chain. Simulated random demand was fed into the inventory policy models to generate inventory costs, calculate resultant profit, and support the evaluation of the effectiveness of specific inventory management policies. The inventory costs and profit results for each of the two inventory management policies was used to derive managerial insight into the effectiveness of these policies and of the impact that transshipments had on supply chain system profit.

The proposed inventory models described a two-echelon supply chain with a centrally located warehouse that served three geographically dispersed supply points. In all cases the supply points serviced their own customers and did not compete for customer demands. The central warehouse received and distributed a stock of single high value items to each of the supply points at the beginning of each scheduled supply period. A graphical depiction of the supply chain is shown in *Figures 1* and *2*.

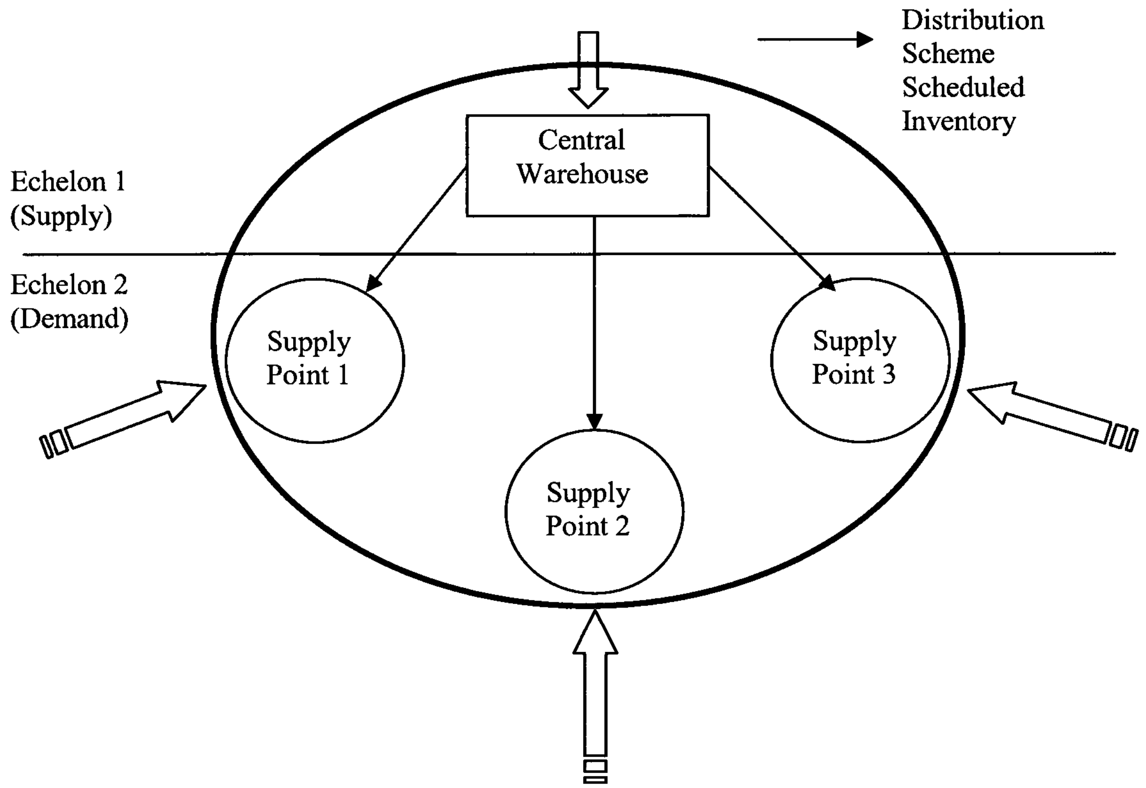

Figure 1. Two-echelon Supply Chain Model without Transshipment

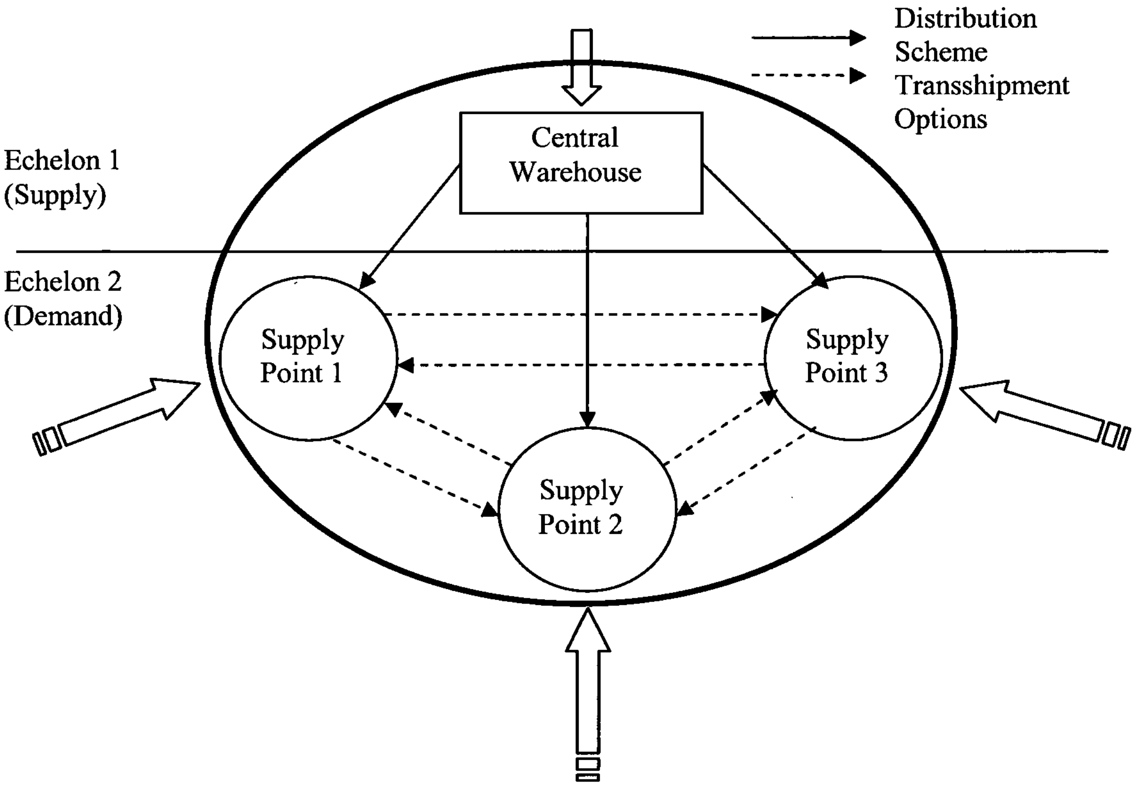

Figure 2. Two-echelon Supply Chain Model with Transshipment

Operating within specified problem parameters and assumptions, 30-day blocks of simulated demand data were generated from the pseudorandom integer generation algorithm as random demand input for the model. The benefit of this approach was that a 100% sample could be taken based on the derived random demand data. Trial runs were used to test and validate the procedures, check mathematical calculations and to identify and correct any problems with the model. Conducting trial runs allowed the researcher to gather and analyze feedback on the process and helped to eliminate bias (Zikmund, 2003). Numerical analysis, based on the dynamic integer programming approach described by Winston and Venkataramanan (2003), was used to gain insight into the effects of fill rate, inventory cost, and transshipment on profit for each of the model runs.

The comparison of system profit levels provided insight on how transshipment affected profit in each of the inventory management policies. The models constructed for this research were based on a theoretical two-echelon supply chain system. A theoretical system was used to simplify the model complexity and to aid in controlling the study. Chiou (2008) stated that a benefit of modeling theoretical systems was that theoretical systems are more comparable than actual systems, and the knowledge from the study was more generalized than a study from a specific system. Because the model for this study could not be validated by monitoring the actual system, validation of the model was achieved by analyzing the output results for computational accuracy.

Participants

The population for this study consisted of random demand elements generated by the pseudorandom integer generation algorithm defined in Equation 2. This study did not involve human, animal, or any other live subjects. This experimental study was conducted using mathematical modeling and simulation techniques. The inventory management policy models underwent pretesting using a test data set generated by the algorithm described in Equation 2. The pretesting data set provided sample output that was checked to validate the computational accuracy of the inventory model calculations.

Winston (2004) discussed the value of using the normal distribution to model random events. Due to the important role that random demand for inventory plays in this research the minimum sample size for the study was determined using the Normal distribution. Based on a desired confidence level of 95%, a level of maximum variability of $p = .5$ and ± 5% precision the resulting sample size was calculated using Equation 1.

$$N = \frac{Z^2(p)(q)}{e^2} \tag{1}$$

$$N = \frac{(1.96)^2(.5)(.5)}{(.05)^2}$$

$$N = 385$$

The sample size was rounded up to 390 data elements to facilitate the grouping of data into 30 element blocks representing 30 days of demand.

Materials/Instruments

Several standard Microsoft Excel spreadsheet functions were used to develop a pseudorandom integer algorithm, described in Equation (2) that generated a set of pseudorandom integers between zero and five to simulate daily supply point demand.

dRANDS = ABS((ROUND(RAND( ),1)*10)-5) (2)

Equation (2) was used to generate the pseudorandom integer values. The RAND( ) function returned an evenly distributed random number greater than or equal to 0 and less than 1. The ROUND(, 1) function rounded the elements of dRANDS to the nearest integer. The Absolute value, ABS( ) provided positive values for all elements of dRANDS. The randomness of the generated integers was tested and verified using the Wald-Wolfowitz runs test performed on statistical software written by Arsham (2005). This test was used to verify the true randomness of the numbers. The random demand data set was displayed in Appendix A.

Model formulations. Building models that quantify the costs associated with inventory required a clear understanding of the costs associated with holding inventory. Holsenback and McGill (2007) defined inventory holding cost as the variable cost of keeping inventory on hand. Inventory holding cost was commonly expressed as a percentage of the item's value due to the difficulty of precise determination (Holsenback & McGill, 2007; Stock & Lambert, 2001). This percentage costing assumed that inventory holding cost was linearly proportional to the amount of inventory held. The cost variables considered in this study were defined as follows.

Backorder Costs (C_b) – the cost incurred by a business when it was unable to fill an order with on hand stocks and must complete it later.

Inventory Carrying Cost (C_c) – the cost of holding an item in inventory which included the costs for storage facilities, handling, insurance, pilferage, breakage, obsolescence, depreciation, taxes, and opportunity cost of capital.

Item Cost (C_i) – the cost per item.

Ordering Cost (C_o) – the cost associated with replenishing inventory.

Stockout Cost (C_s) – the temporary or permanent loss of sales when demand cannot be met. The stockout cost takes into account the situations in which customer demand cannot be immediately satisfied. Ballou and Burnetas (2003) estimated that stockouts result in lost sales approximately 25% of the time and the remaining 75% result in a backorder.

Transportation Cost (C_t) – the cost of transporting inventory from the point of supply to the point of demand.

Transshipment Costs (C_{ts}) – the cost associated with transferring inventory between supply points.

Lost Profit (π) – the potential profit that could be gained by selling excess inventory.

Quantity Demanded (Q_d) - demand for inventory presented at a supply point.

Quantity Excess (Q_e) – amount of positive inventory after demand has been met.

Quantity Short (Q_s) – amount of negative inventory after demand occurs.

The following notation was used to formulate the total cost equation for the Standard Inventory Policy:

Backorder Costs $(C_b) = (C_i + C_o + C_t)$ (3)

Stock Out Cost $(C_s) = Q_d\,[(.25C_i) + (.75C_b)]$ (4)

The cost of unsold inventory = $Q_e\,(C_c)$ (5)

Total Cost for Standard Inventory Policy (TC_{st}) *= Cost of Inventory Sold + Cost of Inventory Shortage + Cost of Unsold Inventory*

$TC_{st} = Q_d\,(C_c + C_i + C_o + C_t) + Q_s\,(C_b + C_s) + Q_e\,(C_c)$ (6)

Cost Formulations for the shared inventory policy are shown in the following equations:

Backorder Costs $(C_b) = (C_i + C_o + C_{ts})$ (7)

Stock Out Cost $(C_s) = [(.25 \text{ x } Q_d \text{ x } C_i) + (.75 \text{ x } Q_d \text{ x } C_b)]$ (8)

Transshipment Cost $(T_c) = Q_t\,(C_{ts})$ (9)

Incentive Cost $(I_c) = Q_t\,(.35C_{ts})$ (10)

Total Cost for Shared Inventory Policy (TC_{sh}) *= Cost of Inventory Sold + Cost of Inventory Shortage + Cost of Unsold Inventory + Cost of Transshipment + Cost of Incentives*

$(TC_{sh}) = Q_d(C_c + C_i + C_o + C_t) + Q_s(C_b + C_s) + Q_e(C_c) + Q_t(C_{ts}) + Q_t(I_c)$ (11)

System profit was defined as total revenue minus total cost. The standard and shared inventory policy profit equations were defined as:

Profit for Standard Inventory Policy (P_{sp}) *= Total Revenue for Inventory Sold – Total Cost of Inventory* (TC_{st})

$(P_{sp}) = Q_d$ (Price of Inventory) - (TC_{st})

$$(P_{sp}) = Q_d (P) - (TC_{st}) \tag{12}$$

Profit for Shared Inventory Policy (P_{sh}) *= Total Revenue for Inventory Sold – Total Cost of Inventory* (TC_{sh})

$(P_{sh}) = Q_d$ (Price of Inventory) - (TC_{sh})

$$(P_{sh}) = Q_d (P) - (TC_{sh}) \tag{13}$$

Validity of the proposed inventory management policy models was achieved by incorporating the previously researched cost model elements described by Ballou and Burnetas (2003), Holsenback and McGill (2007), Stock and Lambert (2001), and by conducting inspections of the data analysis. Numerical confirmation using direct extreme-condition testing was used to ensure that the numerical values were being estimated accurately. Direct extreme-condition testing of the inventory management models involved evaluating the validity of model equations under extreme conditions by assessing the plausibility of the resulting values against the anticipation of what would happen under a similar condition in real life. Unlike normal operating conditions, it was relatively easy to anticipate what values the variables of the real system would take under extreme conditions such as the minimum and maximum expected demand values of 0 and 5. This technique permitted each model equation to be tested by assigning the extreme values to input variables and comparing the value of the output variable to what would logically happen in the real system under the same extreme condition.

Transshipment incentives. Dixit and Nalebuff (1991), Pindyck and Rubinfeld (2005), and Teich et al., (1999), discussed the use of economic incentives to promote cooperation where individual participants must be offered an incentive that leaves them better off after accepting it than if they were to reject it. An assumption of this study was that without incentives individual supply points would not participate in transshipment of inventory. In this study, transshipment was encouraged among supply points by employing an incentive that offered the donor supply point a percentage of the profit gained by the recipient supply point through transshipments.

Normal profit per item was calculated as:

Item Sales Price $(P) - (C_i + C_o + C_c + C_t)$

$$(P_n) = (P) - (C_i + C_o + C_c + C_t) \tag{14}$$

Transshipment profit per unit was calculated as:

Item Sales Price $(P) - (C_i + C_o + C_c + C_t + C_{ts})$

$$(P_t) = (P) - (C_i + C_o + C_c + C_t + C_{ts}) \tag{15}$$

The incentive structure for participation in transshipments was:

Normal Profit = 75% of Item Cost

Profit for Donor Supply Point who Transships = 35% of Normal Profit

Profit for Receiving Supply Point = 65% of Normal Profit

The supply chain manager's challenge was to maximize the profit of the supply chain by minimizing inventory build-up, avoiding excessive holding costs, and achieving high customer service levels. From a systems perspective it was more efficient to reallocate excess units from within the system to satisfy demand shortages than to produce more units (Chase et al., 2006). Supply points holding positive inventory levels in excess of current demand could be encouraged to participate in transshipments through the use of incentives. The supply point that donated excess inventory gained a percentage of profit and in doing so, lowered its carrying cost.

The conventional thought was that transshipments were a proven means of lowering inventory costs (Axsater, 2003; Ballou & Burnetas, 2003; Bell, 2001; Benjaafar et al., 2005; Cachon, 2003; Chiou, 2008; Dong & Rudi, 2004; Grahovac & Chakravarty, 2001; Himden et al., 2007; Porteus, 2002; Qin, 2005; Rudi et al., 2001; Saetta, & Tiacci, 2003; Tagaras, 1989; Zanoni et al., 2005; Zhang, 2005). This thought was based on the assumption that donor supply points would be better off profit wise by participating in transshipments than they would be if they did not participate and recipient supply points would be better off because they can gain a percentage of profit from meeting customer demand that without transshipment would be lost (Dixit & Nalebuff, 1991; Pindyck & Rubinfeld, 2005; Teich et al., 1999). The donor supply point might also be better off if it could avoid paying carrying costs and gain a portion of the margin. From a systems perspective higher customer service levels could potentially be achieved using lower inventory levels when cooperation occured and lower inventory costs were encountered. The research question and hypotheses were designed to test the conventional thoughts on these topics.

Procedures

The goal of this quantitative experimental study was to assess the effects of transshipment on profit in a two-echelon supply chain experiencing random demand. To facilitate this research study mathematical models were constructed for two proposed inventory management policies, the standard and the shared. These two inventory policies were used to assess the effect of transshipment and the resultant profit generated by the inventory policy models.

The following section describes the procedures used to carry out the study.

1. Multiple blocks of simulated random demand for inventory were generated using the pseudorandom integer generation algorithm described in Equation (2). Blocks of demand data consisted of 30 integers that represented daily demand over a 30-day period.
2. Statistical software developed by Arsham (2005) employing the Wald-Wolfowitz runs test was used to verify the true randomness of the generated data.
3. Once the randomness of the data was confirmed 30 day blocks of demand data were fed into the inventory policy models represented in Equations (12) and (13). These models were programmed into Excel spreadsheets which calculated revenue, cost, and the resultant profit based on the random demand data. Several test runs of the models were performed to confirm the mathematical accuracy of the models, the reliability of the numerical calculations, and that a controlled test environment had been established. After each run the model was reset to clear residual data and to ensure calculation consistency and reliability.
4. Multiple model runs were conducted using dynamic programming to step though the model in stages to solve these stages sequentially. A complete model run represented 30 days of inventory activity. The output for each day was captured and used to conduct numerical analysis aimed at comparing the policy model results and assessing the impact of transshipment on profit.

5. The model runs for the standard and shared inventory policy models were numerically analyzed to compare cost and system profit levels achieved by the models.
6. Output data from the model runs was statistically tested using the Wilcoxon Matched Pairs test to test the research hypotheses.
7. Research conclusions based on the analysis of the model outcomes were be presented.

The proposed process is displayed in Figure 3.

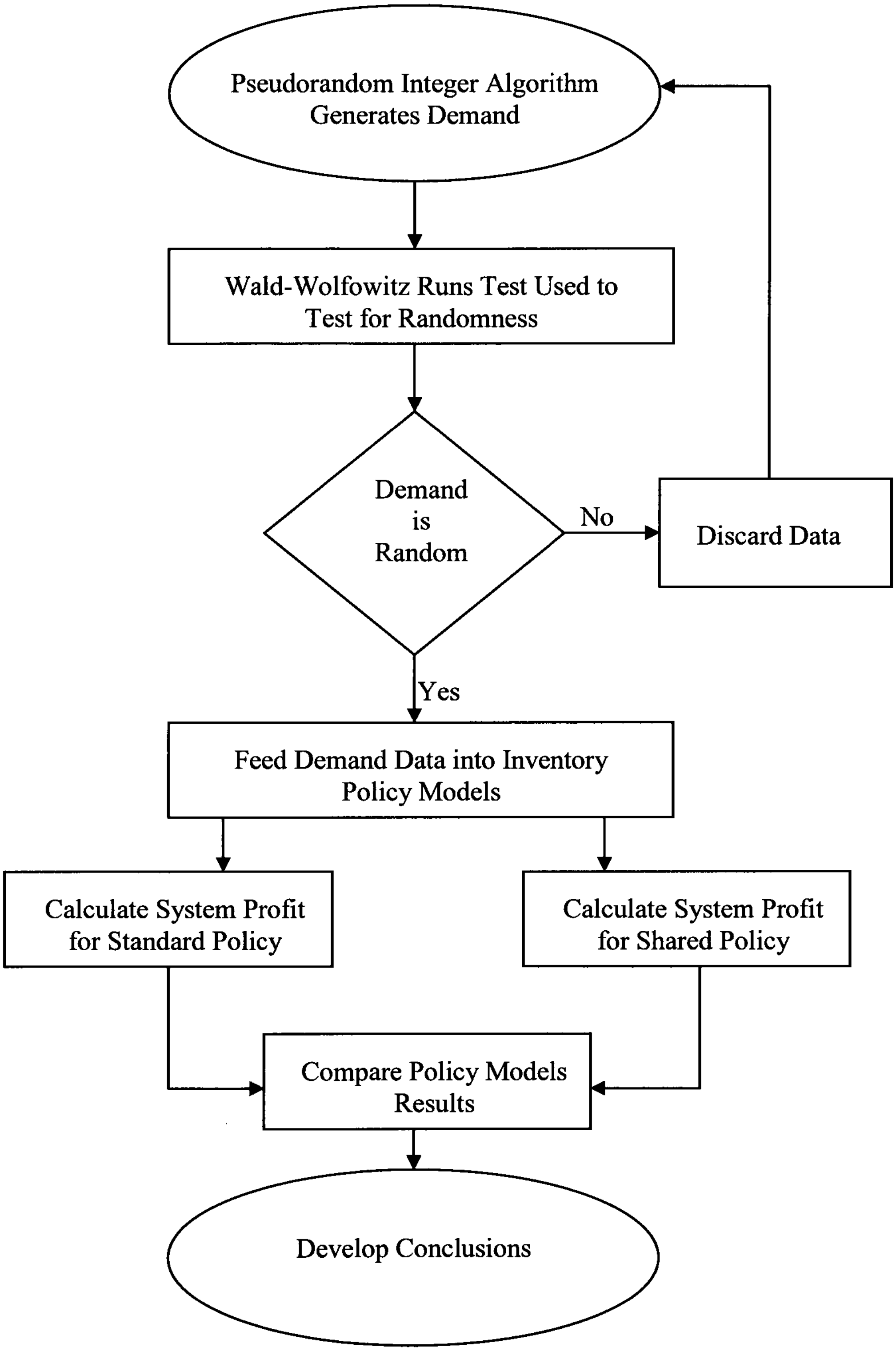

Figure 3. Modeling and Simulation Process Flow

Data Collection, Processing, and Analysis

A pseudorandom integer generation algorithm described by Yi (2005) and Zhang (2005) and defined in Equation 2 was used to provide the random demand data needed to be presented as daily demand at each of the independent supply points being modeled. Simulating random demand was valid for this study because the simulated random demand could be tested and randomness confirmed through statistical tests. A benefit of this approach was that once randomness was confirmed 100% of the sample data set could be used for the experiment. Zhang (2005) described the utility and benefits of modeling random demand to generate simulated daily demand for specific periods. The data processing portion involved inputting the simulated random demand data set into the inventory policy models. The model output was numerically and statistically analyzed to answer the research questions and hypotheses.

The data analysis portion of the study involved numerical and statistical analysis (Wilcoxon Matched Pairs test) of the outputs data from the inventory policy model runs. Modeling provided a mathematical tool to help describe and study the dependent and independent variables identified in this study. Modeling also permited sensitivity analysis to determine the impact of specific variables on cost and profit as well as the ability to repeat experiments and accurately capture data for analysis. Supply chain demand activity was simulated by the random data set. Excel spreadsheets were used to program and execute the inventory management policy models defined in Equations 12 and 13. The MATLAB programming language was used to conduct numerical and graphical analysis of the inventory policy model output.

The dynamic programming method described by Winston and Venkataramanan (2003) was used to break the problem into smaller sub-problems called *stages* and then to solve these stages sequentially. A main benefit of this approach was the ability to recursively work backwards from a solution to analyze and assess the cost and profit impact at each stage in the computation. The first research hypothesis is restated as follows:

$H1_o$. There is no significant difference in total system profit when an inventory policy using transshipment is compared to an inventory policy that does not use transshipment.

$H1_a$. There is a significant difference in total system profit when an inventory policy using transshipment is compared to an inventory policy that does not use transshipment.

To test the first research hypothesis the simulated random demand data set was entered into the standard and shared inventory policy models to obtain cost and profit results. The results of the two inventory policy models were numerically analyzed, and compared to determine which policy achieves better system profit results. The Wilcoxon Matched Pairs test was used to statistically test the hypothesis and help answer the research question. The validity of this approach was achieved by the use of a mathematical modeling methodology that was well-researched and documented. The use of simulated random data allowed for the sampling of the entire data set generated while the use of mathematical modeling permited the experiment to be run as many times as required and to adjust the model to incorporate various assumptions.

For the second research hypothesis, dynamic programming and numerical analysis was used to determine the daily cost and profit calculations for the shared inventory policy model as they related to post transshipment demand. The Wilcoxon test was used to statistically test the second research hypothesis and help to answer the research question.

$H2_o$. There is no significant difference in system profit when an inventory policy using transshipments receives post transshipment demand as compared to an inventory policy that does not use transshipment.

$H2_a$. There is a significant difference in system profit when an inventory policy using transshipments receives post transshipment demand as compared to an inventory policy that does not use transshipment.

A results matrix was used to represent the outcome of demand occurring after a supply point has participated in transshipment. Validity was achieved through the use of a well-researched and documented non-parametric Wilcoxon statistical test. This approach provided a valid means to assess the effect of post transshipment demand on system profit. The outcomes of the results matrix helped to determine the inventory management policy that achieved the optimal profit, cost, and customer service levels.

For the third research hypothesis dynamic programming and numerical analysis was used to determine the daily cost and profit calculations for the shared inventory policy model as they related to incentive payments for transshipments. The Wilcoxon test was used to statistically test the third research hypothesis and help to answer the research question.

$H3_o$. There is no significant difference in system profit when incentives are used to induce voluntary participation in transshipment as compared to an inventory policy that does not use transshipment.

$H3_a$. There is a significant difference in system profit when incentives are used to induce voluntary participation in transshipment as compared to an inventory policy that does not use transshipment.

A results matrix was used to represent the outcome of employing incentives to induce participation in transshipments. Validity was achieved through the use of a well researched and documented non-parametric Wilcoxon statistical test. This approach provided a valid means to assess the effect of incentives on system profit. The outcomes for the results matrix helped to determine the inventory policy that achieves the optimal profit, cost, and customer service levels.

Methodological Assumptions, Limitations, and Delimitations

The assumptions that were critical for the model and the analysis in this study were: (a) demand was random, (b) because of geographic dispersion individual supply points did not compete for customers, and (c) transshipment sources were chosen based on their level of inventory at the time of demand. While other researchers have looked into the use of transshipments to manage inventory levels in two-echelon supply chains, none have addressed how the lack of demand history, the use of incentives, and the occurrence of demand after transshipment may affect system profit. No information from the literature search suggested that such research has been done before.

A limitation of this study was that it represented a simple supply chain consisting of two echelons that may not fully represent some of the relationships found in more complex supply chain systems composed of more than two echelons. To make the study possible through true experimental design, a data set of truly random historical demand values would be available. While the availability of such actual data would be ideal, it was not possible to obtain within the scope of this research study.

To compensate for the lack of historical random demand data, a pseudorandom integer generation algorithm was used to create a sufficient data set of random demand values. Appendix A lists the pseudorandom data set used to make this experiment possible. The delimitation of the study was that while an attempt was made to refute the null hypothesis, a solution that addresses the alternative hypothesis was expected to also be validated with a significant degree of confidence. It was hoped that the findings of this research would increase the knowledge of inventory policies and provide a useful decision tool for inventory managers.

Ethical Assurances

Because no human or live subjects were used in the research no conflict of the ethical principles of scientific value or any requirements for an informed consent of any research subject existed. In addition there was no involvement of commercial or private sponsors that might have benefitted from the outcome of this research. The study was experimental in its entirety and was conducted using mathematical modeling and simulation implementations that met the experimental design. The mathematical modeling and simulation for this study was conducted in a test environment that involved a Dell 630 laptop computer. Therefore, after the experiment was executed no harm was caused to anyone or anything. For the reasons outlined above no potential ethical problems were foreseen. IRB approval was obtained prior to any data collection conducted.

Summary

The purpose of this quantitative experimental study was to assess the impact that transshipments had on a business's ability to minimize inventory costs, maximize system profit, provide adequate customer service levels and address demand uncertainty by mathematically modeling two proposed inventory management policies developed by the researcher. The key concept proposed in this dissertation was the use of mathematical modeling and simulation to assess the effect of transshipment on profit in a two-echelon supply chain using proposed inventory management policy models. Simulated demand data was generated from the random integer generation algorithm and input into the two inventory policy models to generate inventory costs, calculate resultant profit, and support the evaluation of the effectiveness of specific inventory policies in a two-echelon supply chain. The output from the inventory models was compared to gain insight into the effects of fill rate, inventory cost, and transshipment participation on profit.

Numerical analysis based on the dynamic integer programming models described by Winston and Venkataramanan (2003), was used to compare the optimal profit levels for each of the two cases. Incentives proposed by the researcher that were designed to encourage participation in transshipment were assessed to determine how they affected system profit. The output from the inventory management policy models was statistically tested using the Wilcoxon statistical test to answer the research questions and hypotheses. The critical assumptions for the model and the analysis in this study were stated as: (a) demand was random, (b) because of geographic dispersion individual supply points did not compete for customers, and (c) transshipment sources were chosen based on their level of inventory at the time of demand.

Chapter 3 addressed how the proposed research would fill a void in recent literature by addressing how the lack of demand history, the use of incentives, and the occurrence of demand after transshipment may affect system profit. A limitation of the study arose because the modeling of supply chain consists of only two echelons that may not fully represent some of the more complex supply chain relationships. A delimitation of the study dealing with potential solutions resulting from an alternative hypothesis was briefly discussed. The goal of Chapter 3 was to describe the inventory modeling and simulation process that could be used to gain insight into the effects of fill rate, inventory cost, and transshipment participation on profit. The comparison of model results provided insight on how transshipment affected profit under specified inventory policies.

Chapter 4: Findings

The purpose of this quantitative experimental study was to assess the impact that transshipments have on a business's ability to minimize inventory costs, maximize system profit, provide adequate customer service levels and address demand uncertainty by mathematically modeling two inventory management policies developed by this researcher. The analysis of the results generated by the inventory policy models were presented and organized according to the research questions and the corresponding hypotheses questions used to guide this study. Random demand for inventory served as the independent variable and was used in the inventory policy models to generate the values for the dependent variables of cost and profit.

The study findings are presented in three sections. The first section provides information regarding the random data used as the independent variable. The inventory management policy model calculations which were based on the dependent variables of cost and profit were used to address the research questions and hypotheses. In the second section the analysis and evaluation of the impact of random demand, the use of transshipments, and the use of incentives were analyzed and evaluated. A summary of the results of the study were presented in the third section. The evaluation of the findings presented in chapter 4 focused on answering the following three research questions pertaining to the use of transshipments.

Q1. Does an inventory management policy that uses transshipment achieve higher system profit than an inventory management policy that does not use transshipment?

Q2. Does the occurrence of random demand at a supply point after it has donated inventory for transshipment lead to decreased system profit?

Q3. Does the use of incentives to induce participation in transshipment lead to decreased system profit?

Results

To answer the first research question: *Does an inventory management policy that uses transshipment achieve higher system profit than an inventory management policy that does not use transshipment*, blocks of 30 pseudorandom integers were fed into the standard inventory management policy model to simulate 30 days of random demand for each of the three independent supply points. The same blocks of pseudorandom integers were fed into the shared inventory management policy model. The resultant output from the standard and shared inventory management policy models was numerically compared to assess the ability of each inventory management policy model to minimize inventory costs, maximize system profit, and provide adequate customer service levels.

For this study several assumptions were used to facilitate the evaluation of the inventory management policy models. Product fill rates were set below 100% to represent actual supply chain conditions as recommended by Ballou and Burnetas (2003). The inventory levels were replenished every 30 days by the central warehouse which allocated and distributed all products to three supply points. The supply points were located equidistant from the central warehouse and each other and experienced independent and random demand. The inventory management policy models assumed that customers were willing to wait up to 24 hours for an item before purchasing from a competing vendor.

Model Parameters. The following characteristics defined the model parameters for both the standard and shared inventory management policy models:

1. For each model, run time was broken into periods representing a day of demand, the first period being 0 and the final period being 30. The demand was unknown for each of the periods.
2. Supply points were resupplied by the central warehouse during period 0.
3. Each period's demand must be met from inventory within 24 hours or stockout and backorder costs were incurred.
4. The supply point's goal was to maximize profit by meeting demand for periods 1 through 30 with on hand inventory that was fully stocked on period 0.
5. Costs were accrued and allocated on a daily basis.

The system parameters for the inventory policy models are shown in table 1.

Table 1

Inventory Policy Model Parameters

Model Parameters	**Value**
Item Cost (C)	\$1,000
Ordering Cost (C_o)	\$2.00
Inventory Carrying Cost (C_c)	\$25.00
Transportation Cost (T_c)	\$5.00
Backorder Cost (C_b)	\$151.00
Replenishment Lead Time	30 days
Estimated Inventory Required	75
Profit Rate	1.75
Fill Rate	.95
Inventory Level at t(0)	71

The process flow for the standard inventory management policy with independently operating supply points is depicted in Figure 4.

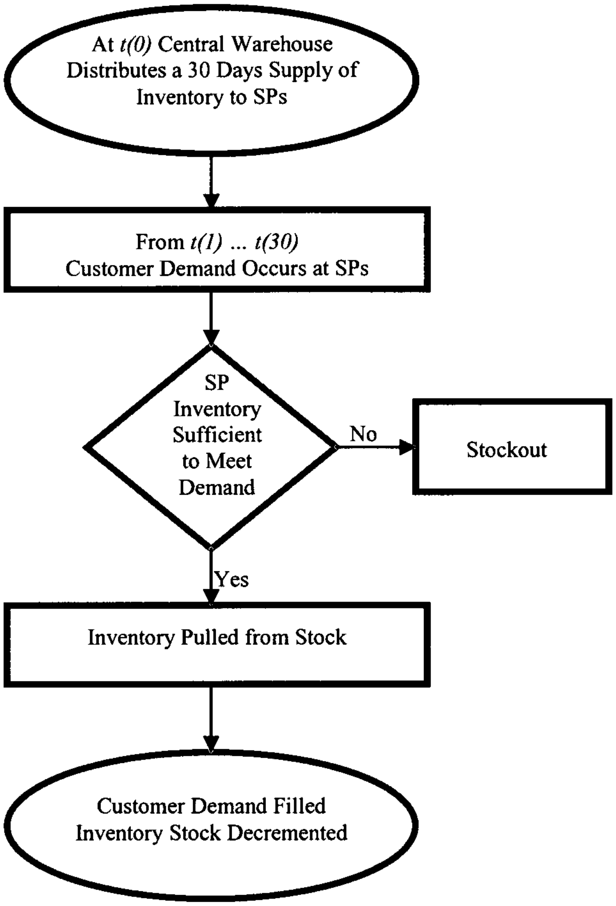

Figure 4. Standard Inventory Management Policy Process Flow

Standard Inventory Management Policy Model

The standard inventory policy model was based on a two-echelon supply chain consisting of one central warehouse serving three independently operating supply points that realized profit by selling a product and earning a profit margin for each item sold. The 30-day blocks of random demand data were input into the standard inventory policy model and the computational results for each model run are shown in Table 2.

Table 2

Demand and Profit Results for the Standard Inventory Policy Model

Run	Location	Simulated Demand	Demand Met	Supply Point Profit	System Profit
1	SP1	78	71	$30,859	$92,931
	SP2	84	71	$25,531	
	SP3	73	71	$36,540	
2	SP1	81	71	$28,269	$108,169
	SP2	70	70	$39,692	
	SP3	70	70	$40,208	
3	SP1	63	63	$33,265	$93,476
	SP2	79	71	$32,228	
	SP3	59	59	$27,983	
4	SP1	95	71	$12,463	$81,414
	SP2	70	70	$39,129	
	SP3	80	71	$29,823	
5	SP1	84	71	$25,231	$94,017
	SP2	65	65	$36,273	
	SP3	62	62	$32,513	
6	SP1	69	69	$37,925	$85,448
	SP2	95	71	$11,382	
	SP3	75	71	$36,141	
7	SP1	75	71	$36,225	$109,211
	SP2	75	71	$35,893	
	SP3	67	67	$37,094	
8	SP1	69	69	$37,404	$84,738
	SP2	85	71	$23,775	
	SP3	52	52	$23,559	
9	SP1	71	71	$39,541	$108,605
	SP2	71	71	$39,655	
	SP3	80	71	$29,409	
10	SP1	51	51	$22,716	$88,744
	SP2	79	71	$30,151	
	SP3	64	64	$35,878	
11	SP1	64	64	$34,234	$110,632
	SP2	71	71	$41,551	
	SP3	65	65	$34,848	
12	SP1	85	71	$23,699	$89,993
	SP2	69	69	$39,073	
	SP3	81	71	$27,221	
13	SP1	70	70	$38,323	$107,679
	SP2	80	71	$30,686	
	SP3	68	68	$38,669	

Figures 5 and 6 graphically depict the average profit results for each of the three independent supply points for the 13 standard inventory policy model runs.

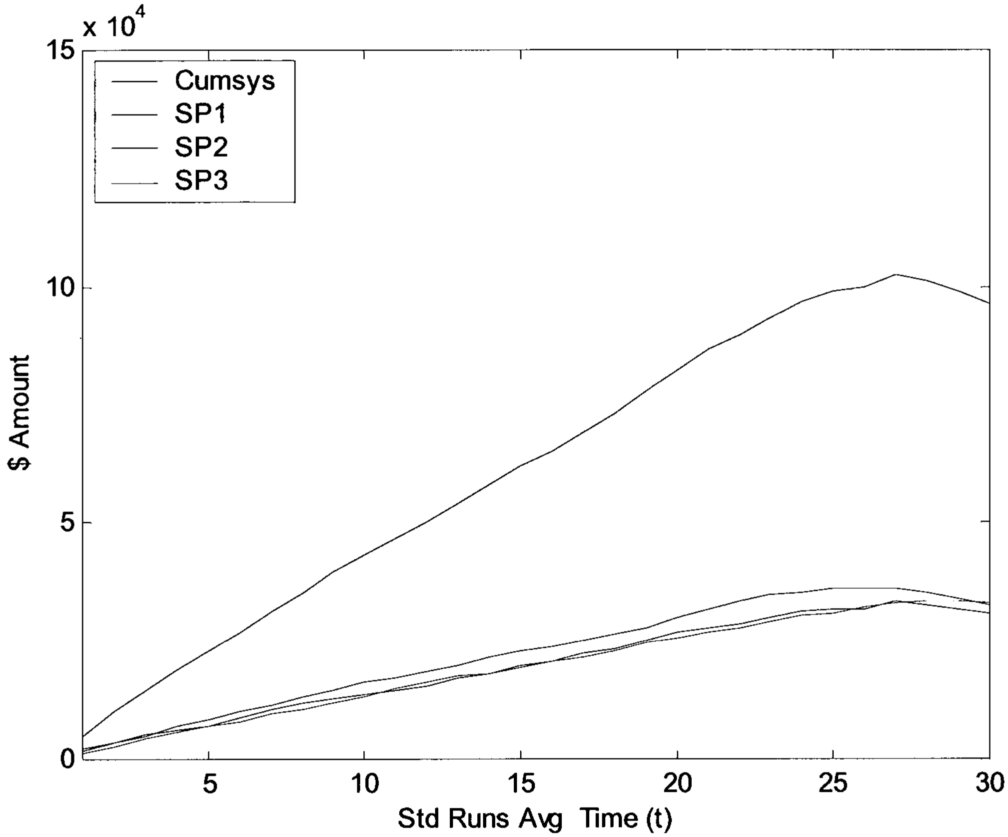

Figure 5. Average Cumulative Profit Results for the Standard Inventory Policy Model

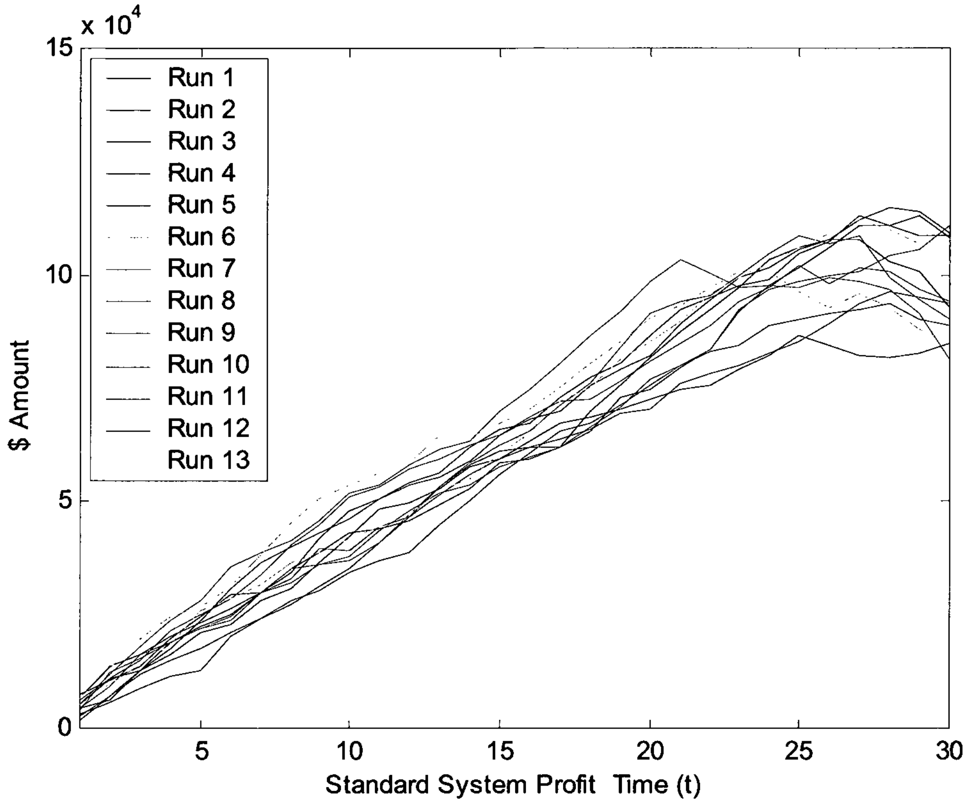

Figure 6. System Cumulative Profit Results for the Standard Inventory Policy Model

Of the 13 runs modeled for the standard inventory policy model there were 39 outcomes for supply point profit. The total simulated demand for inventory was 2,844 units while total available inventory was 2,769 units. In the event where all available units were allocated to filling demand there was a planned deficit of 75 units resulting from a 95% fill rate. The 13 model runs resulted in an actual unmet demand of 186 units. This result represented an excess of 111 units of system wide inventory that were not allocated to meeting demand. In 18 of 39 outcomes a supply point had excess inventory on hand at the end of day 30 while one or more supply points had negative inventory levels on hand at the end of day 30. A total of 111 units of excess inventory were available at the end of day 30. A summary of demand met and demand not met for the 13 model runs is presented in Table 3.

Table 3

Summary of Demand Results for the Standard Inventory Management Policy Model

13 Runs	Simulated Demand	Demand Met	Demand UnMet	Available Inventory
SP1	955	883	72	923
SP2	993	913	80	923
SP3	896	862	34	923
Total	2,844	2,658	186	2,769

Shared Inventory Management Policy Model.

The shared inventory management policy model was based on a two-echelon supply chain consisting of one central warehouse serving three independently operating supply points that realized profit by selling a product and earning a profit margin for each item sold. The shared inventory policy model was based on the theory that economic trading could prevail in a responsible way to maximize system performance while minimizing costs. Under this policy incentives were used to solve inventory problems by making transshipments within the system more attractive for individual supply points rather than holding on to inventories in excess of current demand.

In the shared inventory management policy research, dynamic programming was used to address a series of sequential inventory decisions corresponding to each demand period. The criteria for participating in transshipment were based on supply point inventory levels evaluated at the end of each demand period against an estimated maximum expected demand per period. For this study, a maximum expected demand of five units was used. If the donor supply point inventory level was greater than the maximum expected demand, then the corresponding decision rule stated that the supply point should share the excess inventory. If the donor inventory level was less than the maximum expected demand, the decision rule was not to share excess inventory. The exception to this rule was on day 30 any positive inventory balance was available for transshipment.

Under the shared inventory policy, when random customer demand for an item could not be completely filled from stock at the supply point, supply points would send a transshipment request to the central manager who maintained visibility over system wide inventory. The central manager, based on his knowledge of system wide inventory levels, could assign a transshipment request to the supply point within the system with surplus on-hand inventory to fill the transshipment request. When demand occurred in the shared inventory policy, there were five possible outcomes: (a) the demand was completely met from the stock on-hand, (b) demand was partially met from the stock on-hand, and partially met via transshipment from one or more supply points in the system, (c) demand was completely met by transshipment, (d) demand was partially met from a combination of the stock on-hand and transshipment with some unmet demand amount being placed on backorder, or (e) demand was completely backordered.

For each inventory period, the central decision-maker was responsible for reviewing supply point inventory and demand levels to determine inventory shortages and excesses. Supply points with inventory levels greater than the largest estimated demand of five units, were considered to be a donor and supply points with inventory levels insufficient to meet demand were considered as recipients. If there were multiple donors in a period, the donor with the largest inventory level would donate to the recipient with the greatest unmet demand. For multiple recipients with the same level of unmet demand, the donor would transship available excess inventory equally. The shared inventory policy process flow is shown in Figure 10.

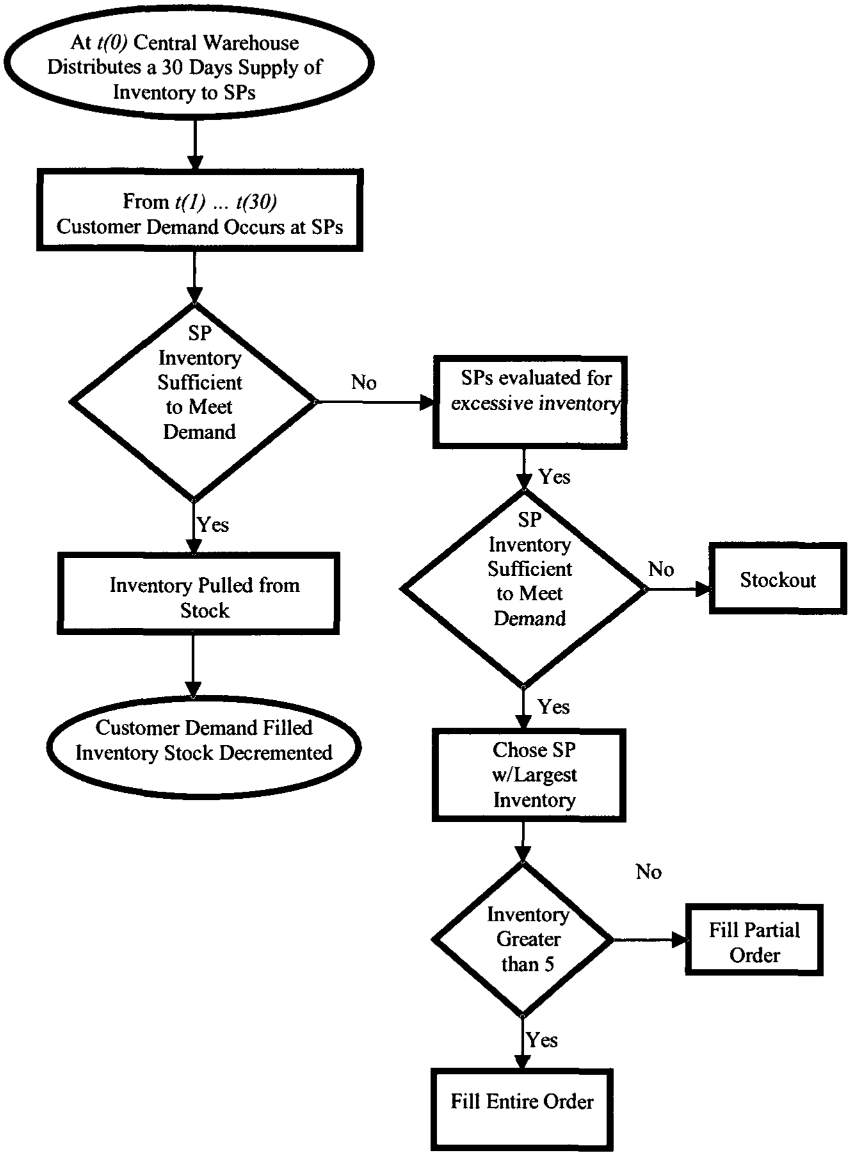

Figure 7. Shared Inventory Policy Process Flow

The 30-day blocks of random demand data were input into the shared inventory policy model and the computational results showing the supply point and system profits for each model run are shown in Table 4.

Table 4

Demand and Profit Results for the Shared Inventory Policy Model

Run	Location	Simulated Demand	Demand Met	Supply Point Profit	System Profit
1	SP1	78	71	$30,859	$98,242
	SP2	84	74	$34,550	
	SP3	73	68	$32,832	
2	SP1	81	73	$34,380	$115,678
	SP2	70	70	$40,390	
	SP3	70	70	$40,907	
3	SP1	63	63	$33,265	$123,597
	SP2	79	79	$56,661	
	SP3	59	59	$33,671	
4	SP1	95	82	$46,109	$103,734
	SP2	70	63	$31,587	
	SP3	80	68	$26,038	
5	SP1	84	84	$64,943	$143,232
	SP2	65	65	$39,067	
	SP3	62	62	$39,222	
6	SP1	69	58	$25,940	$113,217
	SP2	95	84	$51,136	
	SP3	75	71	$36,141	
7	SP1	75	73	$42,333	$124,281
	SP2	75	73	$42,001	
	SP3	67	67	$39,948	
8	SP1	69	69	$37,404	$137,885
	SP2	85	85	$66,546	
	SP3	52	52	$33,935	
9	SP1	71	71	$39,541	$113,992
	SP2	71	68	$35,880	
	SP3	80	74	$38,571	
10	SP1	51	51	$28,463	$118,925
	SP2	79	79	$54,585	
	SP3	64	64	$35,878	
11	SP1	64	64	$34,234	$110,632
	SP2	71	71	$41,551	
	SP3	65	65	$34,848	
12	SP1	85	75	$35,932	$101,336
	SP2	69	67	$38,183	
	SP3	81	71	$27,221	
13	SP1	70	70	$39,022	$122,726
	SP2	80	75	$42,900	
	SP3	68	68	$40,805	

Figures 8 and 9 graphically depict the average profit results for each of the three independent supply points for the 13 standard inventory policy model runs.

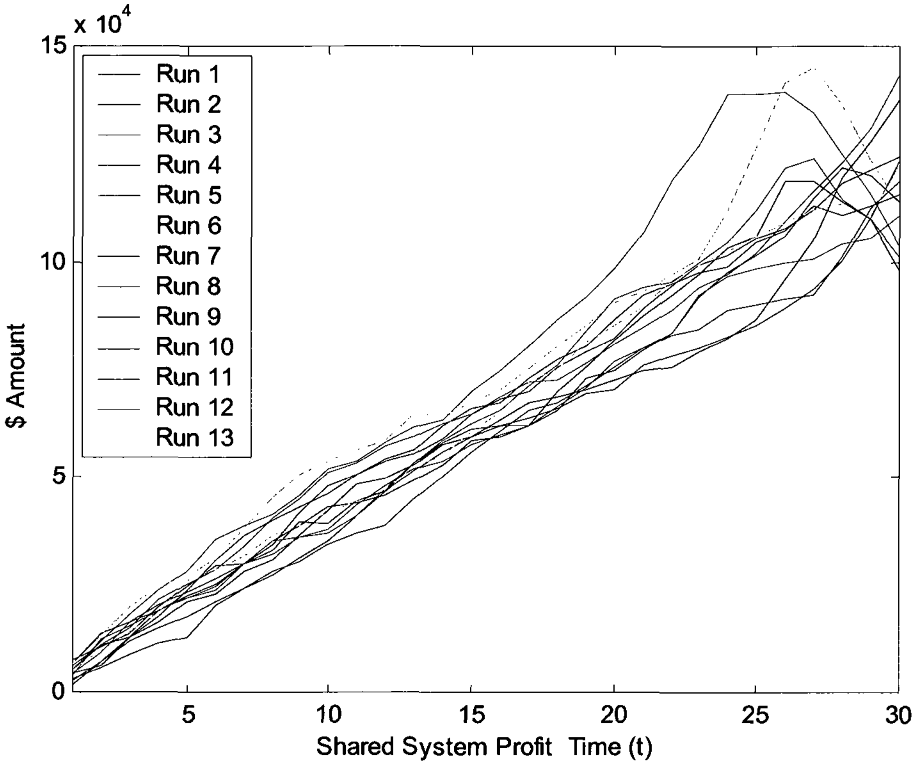

Figure 8. Average Cumulative Profit Results for the Shared Inventory Policy Model

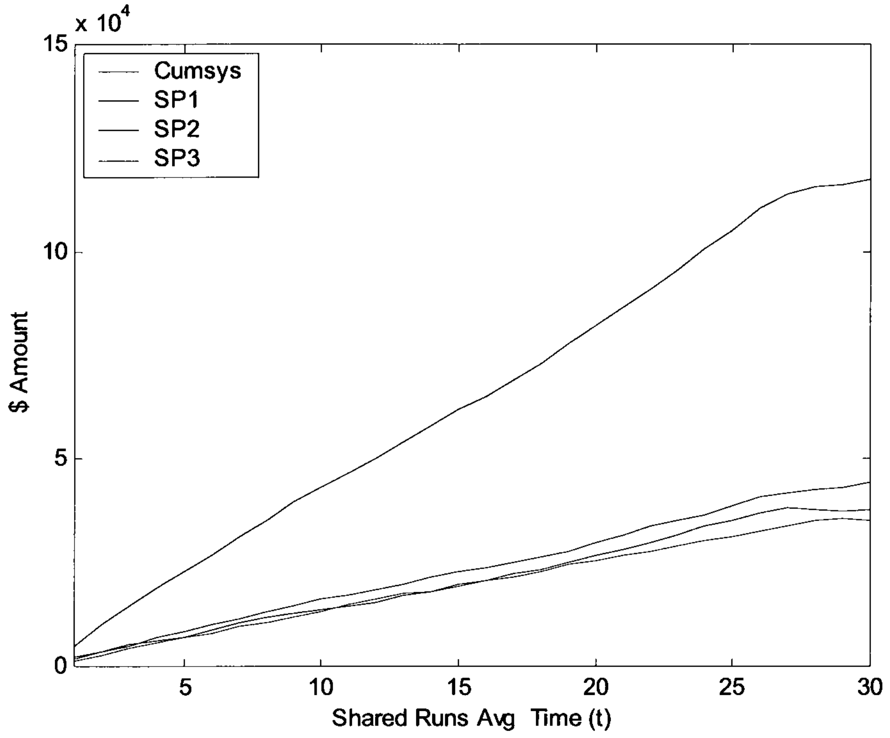

Figure 9. System Cumulative Profit Results for the Shared Inventory Policy Model

Operating under a shared inventory policy, the supply points were incentivized to share excess inventory to maximize system profit by reducing excess inventory and meeting a higher percentage of customer demand. Of the 13 runs modeled in this study there were 39 outcomes for supply point profit. Recall from the standard inventory policy model results that the total simulated demand was 2,844 units while total available inventory based on a 95% fill rate was 2,769 units. In the event where all available units were allocated to filling demand there was a deficit of 75 units. The 13 shared inventory management policy model runs resulted in unmet demand of 128 units. This result showed an excess of 53 units of system-wide inventory that were not allocated to meeting demand. The shared inventory policy resulted in five of 39 outcomes where a supply point had excess inventory on hand at the end of day 30. A total of 53 units of excess inventory were available at the end of day 30. A summary of demand met and demand not met for the 13 model runs is presented in Table 5.

Table 5

Summary of Demand Results for the Shared Inventory Management Policy Model

13 Runs	Simulated Demand	Demand Met	Demand UnMet	Available Inventory
SP1	955	904	51	923
SP2	993	953	40	923
SP3	896	859	37	923
Total	2,844	2,716	128	2,769

A Wilcoxon matched pairs test was conducted on the system profit data presented in Table 6 to statistically determine whether a significant difference existed in total system profit when an inventory policy using transshipment was compared to an inventory policy that did not use transshipment.

Table 6

System Profit Data for 13 Model Runs

	Shared (X_a)	**Standard (X_b)**	**(X_a - X_b)**
Model Run	**System Profit**	**System Profit**	
1	$98,242	$92,931	$5,311
2	$115,678	$108,169	$7,509
3	$123,597	$93,476	$30,122
4	$103,734	$81,414	$22,319
5	$143,232	$94,017	$49,216
6	$113,217	$85,448	$27,769
7	$124,281	$109,211	$15,070
8	$137,885	$84,738	$53,147
9	$113,992	$108,605	$5,387
10	$118,925	$88,744	$30,181
11	$110,632	$110,632	$0
12	$101,336	$89,993	$11,344
13	$122,726	$107,679	$15,048

The results of the Wilcoxon test (W+ = 78, W- = 0, N = 12, $p < .001$) indicated a very strong evidence against $H1_0$.

To answer the second research question: *Does the occurrence of random demand at a supply point after it has donated inventory for transshipment lead to decreased system profit*, the impact of random demand occurring after supply points had participated in transshipment was analyzed. For each instance of transshipment under the shared inventory policy, the occurrence of post transshipment demand was assessed to determine how it affected the amount of system demand met after transshipment. Because each instance of additional demand met positively contributed to profit, the additional demand met served as an indicator of increased profit. Transshipments occurred in 12 of the 13 shared inventory management policy runs modeled in this study.

Of these 12 runs, five runs (41.67%) experienced post transshipment demand that was equal to or greater than the amount of inventory previously transshipped. The remaining seven runs (58.33%) experienced an overall positive outcome of 56 units of demand met resulting from post transshipment demand being less than the amount previously transshipped. The demand results are presented in Table 7.

Table 7

Assessment of Post Transshipment Demand on Profit

Model Run	Qty Donated	Qty Demand Not Met	Additional Demand Met Through Transshipment
1	3	5	0
2	2	0	2
3	8	0	8
4	11	13	0
5	13	0	13
6	13	11	2
7	4	0	4
8	14	0	14
9	2	3	0
10	8	0	8
11	0	0	0
12	4	2	2
13	3	0	3

Transshipments occurred in 12 of the 13 shared inventory policy model runs with no transshipments occurring in the 11th run because demand at each supply point was less than inventory levels. Table 8 presents the transshipment results for the 13 model runs.

Table 8

Post Transshipment Demand Data for 13 Model Runs

Run	Transshipment Qty	Post Transshipment Unmet Demand	System Profit
1	3	5	$98,242
2	2	0	$115,678
3	8	0	$123,597
4	11	13	$103,734
5	13	0	$143,232
6	13	11	$113,217
7	4	0	$124,281
8	14	0	$137,885
9	2	3	$113,992
10	8	0	$118,925
11	0	0	$110,632
12	4	2	$101,336
13	3	0	$122,726

A Wilcoxon two sample test was conducted on the system profit data presented in Table 8 to evaluate whether a significant difference existed in system profit when random demand in excess of inventory levels occured at a supply point after it had donated inventory for transshipment. Based on five runs resulting with unmet post transshipment demand (A = 5) and eight runs with no unmet post transshipment demand (B = 8) the results of the Wilcoxon Two Sample test (A = 5, B = 8, W = 17, $p < .006$) indicated a very strong evidence against $H2_0$.

To answer the third research question: *Does the use of incentives to induce participation in transshipment lead to decreased system profit*, the impact of incentives on system profit was analyzed. To numerically test the hypothesis the shared inventory policy model was adjusted to remove the incentives for transshipments and the same random data set was input into the model to capture the system profit results. Table 9 presents a comparison of the system profit results for 13 runs of the shared inventory management policy model.

Table 9

Transshipment Incentive Data for 13 Model Runs

Run	Supply Point Profit With Incentives	Supply Point Profit Without Incentives	System Profit
1	$30,859	$30,859	$98,242
	$34,550	$31,334	
	$32,832	$36,048	
2	$34,380	$32,237	$115,678
	$40,390	$41,462	
	$40,907	$41,979	
3	$33,265	$33,265	$123,597
	$56,661	$48,086	
	$33,671	$42,246	
4	$46,109	$34,318	$103,734
	$31,587	$40,162	
	$26,038	$29,254	
5	$64,943	$51,008	$143,232
	$39,067	$43,355	
	$39,222	$48,869	
6	$25,940	$39,874	$113,217
	$51,136	$37,202	
	$36,141	$36,141	
7	$42,333	$40,189	$124,281
	$42,001	$39,857	
	$39,948	$44,235	
8	$37,404	$37,404	$137,885
	$66,546	$51,540	
	$33,935	$48,942	
9	$39,541	$39,541	$113,992
	$35,880	$39,096	
	$38,571	$35,356	
10	$28,463	$37,038	$118,925
	$54,585	$46,010	
	$35,878	$35,878	
11	$34,234	$34,234	$110,632
	$41,551	$41,551	
	$34,848	$34,848	
12	$35,932	$31,645	$101,336
	$38,183	$42,470	
	$27,221	$27,221	
13	$39,022	$40,094	$122,726
	$42,900	$38,612	
	$40,805	$44,020	

For each instance of transshipment under the shared inventory policy, the economic impact of the incentives used to encourage individual supply points to participate in transshipment was assessed using two scenarios. In the first scenario the inventory level of the donor supply point was greater than or equal to current demand and thus could be viewed as having a positive post transshipment inventory level. In this scenario, the donor supply point benefited from not having to pay holding costs for the transshipped inventory. The supply point also received an incentive of 35% of the profit to be gained by the recipient supply point's sale of the transshipped inventory.

The recipient supply point benefited from the transshipment by forgoing backorder costs on unmet demand and received 65% of the profit gained by satisfying demand with the transshipment. The overall outcome of transshipment was that both the donor and the recipient supply points increased their profit and reduced cost by participating in the transshipment. The inventory level of the donor supply point was also less than current demand as a result of participating in transshipment and thus could be viewed as having a negative post transshipment inventory level.

In the second scenario the donor supply point incurred lost profit resulting from the backorder costs for the unmet demand that was equal to the amount previously transshipped. The shared profit previously earned from transshipment was less than the full profit the supply point would have made by meeting the post transshipment demand. In 12 of 13 runs modeled in this study incentives were used 39 times to encourage transshipments. Of the 12 model runs involving transshipment, one run resulted in an economic loss and 11 runs resulted in economic gains. The economic impact of demand occurring after transshipment is presented in a results matrix shown in Table 10.

Table 10

Economic Impact of Incentives on Profit

Model Run	Qty Donated	Qty Demand Not Met	Economic Gain	Economic Loss	Outcome
1	3	5	$5,312	$5,350	($38)
2	2	0	$3,541	$0	$3,541
3	8	0	$14,165	$0	$14,165
4	11	13	$19,478	$13,910	$5,568
5	13	0	$23,019	$0	$23,019
6	13	11	$23,019	$11,770	$11,249
7	4	0	$7,083	$0	$7,083
8	14	0	$24,790	$0	$24,790
9	2	3	$3,541	$3,210	$331
10	8	0	$14,165	$0	$14,165
11	0	0	$0	$0	$0
12	4	2	$7,083	$2,140	$4,943
13	3	0	$5,312	$0	$5,312
Total	85	34	$150,508	$36,380	$114,128

The Wilcoxon matched pairs test was used to statistically test the supply point profit data presented in Table 9 to evaluate if use of incentives to induce participation in transshipment lead to decreased system profit. The results of the Wilcoxon test (W+ = 209.50, W- = 225.50, N = 29, $p < .871$) indicated little or no real evidence against $H3_0$.

Evaluation of Findings

The results for all 13 model runs were computed using numerical comparative analysis and the Wilcoxon statistical tests to answer each research question.

Analysis of Research Question 1. The first research question determined if the use of transshipments affected system profit in a two-echelon supply chain. Research Question 1 and the related hypotheses are as follows:

Q1: Does an inventory management policy that uses transshipment achieve higher system profit than an inventory management policy that does not use transshipment?

H1$_o$. There is no significant difference in total system profit when an inventory policy using transshipment is compared to an inventory policy that does not use transshipment.

H1$_a$. There is a significant difference in total system profit when an inventory policy using transshipment is compared to an inventory policy that does not use transshipment.

The observed results presented in Table 11 show a numerical comparison of the mean results for the standard and the shared inventory policy model system profit outcomes for the 13 model runs.

Table 11

Mean Total System Profit Outcomes for 13 Model Runs

	Standard Inventory Policy	**Shared Inventory Policy**
Mean System Profit	$96,543	$117,498
Standard Deviation	$10,753	$13,207
Standard Deviation as a % of the Mean	11.14%	11.24%
Range of Profit	$29,218	$44,990

Numerical comparison of the standard inventory management policy and shared inventory management policy runs results summarized in Table 3 showed that the shared policy achieved a 17.83% higher mean system profit, a 18.58% higher standard deviation of mean system profit, and a 35.10% larger range of system profits for the 13 runs than the standard inventory policy. The standard deviation as a % of the mean was comparable between the two inventory management policies. As a measure of customer service or fill rate the inventory overages and shortages for each model run were presented in Table 12. The lower left corner of each matrix cell shows the system demand (SysD) and the satisfied or met demand (MetD) for each of the inventory management policies while the upper right corner of each policy cell shows the inventory excess (InvExcess) and inventory shortage (InvShortage) levels for each of the inventory management policies.

Table 12

System Payoff Matrix for 13 Model Runs

	Standard Policy		**Shared Policy**	
Model Run	*InvExcess/ InvShortage*	*SysD/ MetD*	*InvExcess/ InvShortage*	*SysD/ MetD*
1	0/-22	235/213	0/-22	235/213
2	+2/-10	221/211	0/-8	221/213
3	+20/-8	201/193	+12/0	201/201
4	+1/-33	245/212	0/-32	245/213
5	+15/-13	211/198	+2/0	211/211
6	+1/-28	239/211	0/-26	239/213
7	+4/-8	217/209	0/-5	217/213
8	+21/-14	206/192	+7/0	206/206
9	0/-9	222/213	0/-9	222/213
10	+27/-8	194/186	+19/0	194/194
11	+13/0	200/200	+13/0	200/200
12	+2/-24	235/211	0/-22	235/213
13	+2/-24	235/211	0/-5	218/213

The system results matrix revealed that the use of transshipments improved the amount of demand met in the system in 10 of the 13 model runs (76.92%). In each of these model runs one or more of the supply points had excess inventory and one or more had inventory shortages. In model Run 11 there was also no change in system profit or fill rates because there were no transshipments due to demand at all three supply points being less than on hand inventory quantities.

The findings from this study agreed with the finding of Himden et al. (2007) and showed that transshipment provided an effective mechanism for correcting inventory discrepancies between locations and improving fill rates. The study findings also agreed with those of Wong et al. (2005) by demonstrating the cost savings generated by transshipment as holding costs and backorder costs were reduced. The results of the 13 model runs revealed that significant differences existed in the total system profit when the standard inventory policy was compared to the shared inventory policy. The comparison between standard and shared policies showed that system profit was higher and the system demand satisfied was greater for the shared than for the standard policy.

The results of the Wilcoxon test ($W+ = 78$, $W- = 0$, $N = 12$, $p < .001$) indicated a very strong evidence against $H1_0$. Therefore, the null hypothesis ($H1_0$) was rejected, and it was concluded that there was a significant difference in total system profit when an inventory management policy using transshipment was compared to an inventory management policy that does not use transshipment. The results of this analysis added to the current knowledge of transshipment by mathematically modeling the effects of transshipment showing that supply points acting independently maximized their own profits and their inventory choices did not, in general, maximize system profit. This research contributed to current knowledge by emphasizing the importance of considering backorder and inventory holding costs in inventory management policies.

Analysis of Research Question 2. The second research question was used to determine if differences existed in system profit when an inventory policy using transshipments received post transshipment demand. Research Question 2 and the related hypotheses were as follows:

Q2: Does the occurrence of random demand at a supply point after it has donated inventory for transshipment lead to decreased system profit?

$H2_o$. There is no significant decrease in system profit when random demand occurs at a supply point after it has donated inventory for transshipment.

$H2_a$. There is a significant decrease in system profit when random demand occurs at a supply point after it has donated inventory for transshipment.

For the 13 Model runs transshipment resulted in 85 units of inventory being applied to meet demand. Post transshipment demand resulted in 34 units of inventory being place on backorder with the overall positive result of an additional 51 units of inventory demand being met through transshipment. In runs 1, 4, 6, 9, and 12 post transshipment demand occurred that was greater than the amount of inventory transshipped. Results of the model runs showed that transshipments which occurred in a period decreased that period's inventory holding and backorder costs and increased profit. The results indicated that due to the decrease in holding backorder costs transshipments reduced the risk of supply points participating in transshipment, even when faced with post-transshipment demand.

Based on five runs resulting with unmet post transshipment demand (A = 5) and eight runs with no unmet post transshipment demand (B = 8) the results of the Wilcoxon Two Sample test ($A = 5$, $B = 8$, $W = 17$, $p < .006$) indicated a very strong evidence against $H2_O$. Therefore, the null hypothesis ($H2_O$) was rejected, and the conclusion made that there was a significant difference in system profit when random demand occured at a supply point after it had donated inventory for transshipment. These results added validity to the research by Huang, Chen, and Wu (2006) by indicating that transshipment was not always optimal when post-transshipment random demand occured. These results added to the current knowledge of transshipment by identifying the need to consider the impact of post-transshipment random demand and by providing an inventory management policy model that could be used as a tool to perform what-if analysis of transshipment activity and the potential impact on individual supply point and system profit.

Analysis of Research Question 3. The third research question was used to determine if differences existed in system profit when incentives were used to induce voluntary participation in transshipment. Research Question 3 and the related hypotheses were as follows:

Q3: Does the use of incentives to induce participation in transshipment lead to decreased system profit?

$H3_o$. There is no significant decrease in system profit when incentives are used to induce participation in transshipment.

$H3_a$. There is a significant decrease in system profit when incentives are used to induce participation in transshipment.

An assumption used in this study was supply points would not participate in transshipment unless they believed it was in the best operational interest of the supply point to do so. Assuming that supply points decided to transship when they were better off under transshipment, and declined to participate in transshipment when they were going to be worse off, the outcome for participation in transshipment can be described as a two stage game. In the first stage the donor supply point had excess inventory while the recipient supply point had a shortage. Transshipment in the first stage benefited both donor and recipient supply points. Each gained a percentage of the profit, incured lower costs, by participating in transshipment which resulted in higher system profit.

The second stage occured when subsequent post transshipment demand that was greater than current inventory levels arrived at the donor supply point. The donor supply point would then lose a portion of the previous transshipment benefit by incurring backorder costs and forgoing the full profit it could have earned by satisfying demand compared to the 35% of the profit it earned by participating in transshipment. In this stage the donor supply point experienced a decrease in profit while recipient supply point that previously benefited from the transshipment was not affected. Table 13 presents the relative economic effect of transshipment incentives on system profit for the two stages.

Table 13

Economic Effect of Transshipment Incentives on System Profit

	Stage 1		**Stage 2**		
Model Run	**Donor Profit**	**Recipient Profit**	**Donor Profit**	**Recipient Profit**	**System Outcome**
1	+	+	-	0	+
2	+	+	0	0	+
3	+	+	0	0	+
4	+	+	-	0	+
5	+	+	0	0	+
6	+	+	-	0	+
7	+	+	0	0	+
8	+	+	0	0	+
9	+	+	-	0	+
10	+	+	0	0	+
11	0	0	0	0	0
12	+	+	-	0	+
13	+	+	0	0	+

The comparison revealed that while individual supply point profit values differed the system profit values were identical. Analysis of the comparison revealed that incentives should be viewed as a zero sum game (Pindyck & Rubinfeld, 2005) in which the sharing or redistribution of profits was used to encourage participation in transshipment. While incentives affected the profit levels of individual supply points the system profits were not affected. These results agree with those of Saetta and Tiacci (2003) who studied the use of negotiation mechanisms to promote transshipment of excess inventory to deficient supply points.

The results of the Wilcoxon test ($W+ = 209.50$, $W- = 225.50$, $N = 29$, $p < .871$) indicated little or no real evidence against $H3_0$. Therefore, the null hypothesis ($H3_0$) failed to be rejected, and it was concluded that there was no significant difference in system profit when incentives were used to induce participation in transshipment.

The findings supported and expanded on the research conducted by Saetta and Tiacci (2003) by proposing and evaluating a specific incentive using a profit sharing plan aimed at encouraging participation in transshipment. The results of this research and conclusion contributed to the field of inventory management by providing an analysis of how incentives affected system profit and how they facilitated participation in transshipment. The inventory management policy models provided a useful tool that could be used to evaluate the impact of incentives on profit and aid in decision making.

Summary

Mathematical modeling was used to simulate the performance of two inventory management policies developed by the researcher and quantitatively measure the impact that transshipments had on inventory costs, customer service level and system profit. The key features of the analysis were: (a) the comparison of two inventory management policy models to assess their ability to satisfy customer demand, minimize cost, and maximize system profit; (b) the analysis of the effect post transshipment demand had on system profit; and (c) the analysis of the effect that the use of incentives to participate in transshipment had on system profit. To answer the research questions random demand data was input into the standard and shared inventory management policy models for 13 model runs. The computational results showing the supply point and system profits for each model run were numerically compared and tested using the non-parametric Wilcoxon statistical tests to answer each research question.

For Q1 the numerical results indicated that there was a difference in system profit when the results of the standard and shared inventory policies are compared. The shared inventory management policy achieved a higher system profit than the standard inventory management policy. The use of transshipments improved the amount of demand met in the system in 12 of the 13 model runs (92.31%). The numerical comparison between standard and shared policies showed that system profit was higher and the system demand satisfied was greater for the shared than for the standard policy. Based on the results of the Wilcoxon test ($p < .001$) the null hypothesis ($H1_0$) was rejected and it was concluded that there was a significant difference in system profit when an inventory policy using transshipment was compared to an inventory policy that does not use transshipment.

For Q2 the numerical results indicated differences existed in system profit when an inventory policy using transshipments received post transshipment demand as compared to an inventory policy that did not use transshipment. Based on the results of the Wilcoxon test ($p < .006$) the null hypothesis ($H2_0$) was rejected and the conclusion made that there was a significant difference in system profit when an inventory policy using transshipments receives post transshipment demand. For Q3 the numerical results indicated a difference in individual supply point profits but no differences existed in system profit when incentives were used to induce participation in transshipment. Based on the results of the Wilcoxon test ($p < .871$) the null hypothesis ($H3_0$) failed to be rejected and it was concluded that there was not a significant difference in system profit when incentives are used to induce participation in transshipment.

The results of the numerical and statistical analysis for both the shared and standard inventory management policies indicated that the shared policy provided significant improvement in system profit over the standard inventory policy. The research results confirmed the findings of Cachon (2003) and indicated that when the supply chain inventory levels were coordinated and profits shared, transshipment was beneficial to participants. The research results agreed with the findings of Dong and Rudi (2004), and Zhang (2005), who showed that by providing a better match between supply and demand, transshipment could improve the performance of the supply chain. In summary, it was shown that potential cost savings and higher system profit could be achieved by participating in transshipment. Supply chain managers could use these results to help understand the complexities involved in such analyses; the economics of transshipment versus non-transshipment; and factors affecting transshipment.

Chapter 5: Implications, Recommendations, and Conclusions

Demand uncertainty and the amount of inventory held by a business can directly affect that business's ability to maximize profit and meet required levels of customer service and availability. According to Holsenback and McGill (2007) inventory costs could represent one-third to one-half of a company's assets and account for a significant portion of the total cost of doing business. Demand uncertainty and the costs associated with holding inventory have a direct effect on a business's profit by tying up cash flow (Himden et al., 2007; Rudi et al., 2001).

A review of literature revealed that transshipment was thought to be a cost effective method of dealing with demand, satisfying customer service levels, and reducing inventory levels. A shortcoming of the reviewed literature was that few transshipment studies considered the problem of random demand occurring at supply points after transshipment occurred and the effect it had on system profit. The reviewed literature also did not address incentives that might be required to encourage the supply points to forego the potential risk of participating in transshipments.

The purpose of this quantitative experimental study was to assess the effect of transshipment on profit in a theoretical two-echelon supply chain. This study measured the ability of two proposed inventory management policies that were developed by the researcher, the standard and shared, to minimize costs and maximize profits. The key concept proposed in this quantitative experimental study was the formulation and use of inventory management policy models and mathematical modleing to assess the effect of transshipment on profit in a two-echelon supply chain.

The two inventory management policies were used to model how transshipments among independent supply points affected profit and to create verifiable cost and profit estimates. Using simulated demand data as input for the inventory management policy models the resultant inventory levels, cost, and profit outcome for the two cases were numerically compared and statistically analyzed to answer the research questions and hypotheses. The analysis of the inventory management policies presented in this study provided evidence to support the use of transshipment as a management strategy. These findings might significantly alter the perception of many managers and practitioners and provide them with a better understanding of how to successfully develop and implement an inventory management policy to obtain the best results.

A limitation of this study was that it represented a simple supply chain consisting of two echelons that may not fully represent some of the relationships found in more complex supply chain systems composed of more than two echelons. To make the study possible through true experimental design, a data set of truly random historical demand values would be available to be used. While the availability of such actual data would be ideal, it was not possible to obtain within the scope of this research study. Chapter 5 contains a discussion of the research questions and hypotheses and research question was discussed and conclusions were drawn from the findings. The remaining portions of chapter 5 cover the implications of the research, recommendations for practical application of this study and possible future research, and conclusions.

Implications

The problem of determining the correct inventory levels to minimize costs and maximize profits becomes difficult when demand is uncertain and no prior demand history for inventory exists (Holsenback & McGill, 2007). High levels of customer service often required correspondingly high levels of inventory (Qin, 2005). Holsenback and McGill identified two significant challenges facing businesses: (a) balancing the efficiency and responsiveness of inventories to provide a high level of customer service without accruing excessive investment in inventory, and (b) optimizing inventory levels to maximize profit. The simultaneous management of inventory and customer service was important because they both directly influence a business's ability to maximize profit (Chou et al., 2006; Dong & Rudi, 2004; Zhang, 2005).

When operating in an environment of demand uncertainty supply chain managers must rely on their own intuition and might not make the right decisions regarding inventory levels. Addressing this problem, the findings presented in this study provided supply chain managers with an important understanding of the benefits of transshipment. This study expanded on previous research by addressing how demand that occured after transshipment contributed to cost and profit. Research generally assumed that transshipments occur as needed (Axsater, 2003; Ballou & Burnetas, 2003; Chou et al., 2006; Dong & Rudi, 2004; Grahovac & Chakravaty, 2001; Porteus, 2002; Van Houtum et al., 2005) and failed to consider the case where independently operating supply points did not freely share excess inventory and may need to be enticed to do so through an incentive.

The implications obtained from analyzing the output from the inventory management policy models for each question are as follows. *Research question Q1: Does an inventory management policy that uses transshipment achieve higher system profit than an inventory management policy that does not use transshipment?* Tagaras

(1989) determined that participation in transshipments can lead to cost reductions and improved service without necessarily increasing system-wide inventories. Ballou and Burnetas (2003) found transshipments to be an effective method of reducing safety stock levels while maintaining high customer fill rates. Dong and Rudi (2004) proposed transshipment as a mechanism to better match supply and demand for the specific case where supply lead time is long and demand at each supply point is difficult to predict.

Rudi et al. (2001) concluded from their research that the optimal inventory orders increased with transshipment prices and optimal inventory order choices for individual supply points did not necessarily maximize system profit. Grahovac and Chakravarty (2001) and Himden et al. (2007) determined that transshipment was an effective inventory collaboration method that could achieve inventory cost reductions. Benjaafar et al. (2005) argued that the percentage cost reduction from transshipment becomes insignificant and a pooled system offered no relative advantage to a distributed one. The majority of the research conclusions contained in the literature presented transshipment as an effective mechanism for correcting discrepancies between a locations' observed demand and the available inventory and as an effective method of reducing safety stock levels while maintaining high customer fill rates.

The study results revealed that system profit was higher and the system demand satisfied was greater when an inventory policy using transshipment was compared to an inventory policy that did not use transshipment. The results shown in the findings of this study indicated that transshipment was an effective tool for reducing inventory levels, maintaining customer service levels, minimizing cost, and maximizing system profit in the face of uncertain demand. Consequently, the implication of the findings of research question Q1 was that supply chain managers who desired to minimize cost and maximize system profit should consider the use of transshipments. Despite the fact that this study examined a simple supply chain composed of two echelons the results should be valid for more complicated supply chains composed of three or more echelons.

Research question Q2: Does the occurrence of random demand at a supply point after it has donated inventory for transshipment lead to decreased system profit? Ballou and Burnetas (2003) researched inventory demand but failed to consider the case where no demand history for a product existed and demand was stochastic. The authors based their analysis on the simplifying assumption that initial demand forecast were possible because of the existence of historical data. Holsenback and McGill (2007) provided an expanded approach from that of Ballou and Burnetas by advocating the importance of the statistical nature of demand to determine proper inventory levels. They concluded that service levels should be assigned to stock based on the demand variance instead of cost and that unnecessarily high service levels resulted in excess inventory and increased carrying costs. None of the studies in the literature review conducted for this research examined the impact of random demand occurring at a supply point after it had participated in transshipment.

A common theme seen in the literature review was that the researchers utilized probability distributions to estimate quantifiable demand during a specified time period and neglected the occurrence of random demand, particularly after participation in transshipment. The implication of the findings for research question Q2 was that the benefits to be gained by participating in transshipment could be negatively affected by random demand occurring after transshipment. Research results for this study supported the findings by Huang et al. (2006) by indicating that transshipment were not always optimal when post-transshipment random demand occured.

Research question Q3: Does the use of incentives to induce participation in transshipment lead to decreased system profit? Gunasekarana et al. (2004) observed that the discrete sites in a supply chain did not maximize efficiency if each pursued goals independently. Fu and Piplani (2004) provided a different view and noted that while a lack of cohesion destroyed value in the supply chain collaboration created value opportunity which could drive effective supply chain management. The authors argued that to be effective, collaboration mechanisms must be able to influence the decisions in supply chains. Cachon (2003) explored the use of revenue sharing and identified several limitations that could be used to explain why revenue sharing was not prevalent in all industries, suggesting that the amount of variability in supply chain demand affected the revenue-sharing performance and high levels of variability may not justify the cost of revenue sharing's administrative burden.

Simatupang and Sridharan (2002) concluded that although partnerships promised mutual benefits, they were rarely realized and that concern for profit from a local perspective coupled with the opportunistic behavior caused a mismatch between supply and demand. The implication of the research question Q3 findings was that while incentives affected the profit levels of individual supply points the system profits were not affected and the incentives used to encourage transshipment did not result in significant differences in system profit.

Recommendations

Based on the conclusions and results obtained during the completion of this study, supply chain managers should consider using transshipment as a means of lowering inventory levels and costs, improving customer fill rates, and maximizing system profit. The primary reason for engaging in transshipment was the increased benefits gained from effectively managing inventory and costs under conditions of demand uncertainty. The numerical and statistical results suggested that transshipment was generally an effective method of minimizing cost, meeting customer service levels and maximizing profit. Transshipment was less effective in cases when post transshipment demand occured after supply points had participated in transshipment. The two inventory management policy models presented in this study supported the incorporation of demand variability into inventory management evaluation and provided a useful tool for conducting what-if analysis for cost and transshipment decisions.

The findings from this study were the first steps to understanding how transshipment affected inventory management and the ability to minimize cost and maximize system profit under demand uncertainty. Because the study concentrated on a simple supply chain consisting of two echelons, future research should expand into more complex supply chains consisting of three or more echelons as are commonly found in competitive retail supply chains. This study was designed to assess, through mathematical modeling and simulation, two inventory management policies using simulated random demand.

The inventory management policy models next should be tested using actual historical demand data collected from industry. Future research could investigate if additional decision rules defining when to participate in transshipment would optimize system profit. As an example, decision rules could incorporate a risk estimate for the probability or post transshipment demand occurring.

Conclusions

A quantitative experimental analysis of two inventory management policy models using simulated random demand data supported statistically ($p < .001$) that there was a significant positive difference in system profit when an inventory management policy using transshipment was compared to an inventory management policy that did not use transshipment. The analysis also supported statistically ($p < .006$) that there was a significant negative difference in system profit when random demand occured at a supply point after it has donated inventory for transshipment and supported statistically ($p < .871$) that there was no significant difference in profit when incentives were used to induce participation in transshipment.

The implication of the findings within this study were that transshipment should be used by supply chain managers as an important tool to minimize cost, meet required customer service levels, and maximize system profit. Random demand played an important role in the effectiveness of transshipment and the risk of random demand occurring after transshipment should be carefully considered. The use of incentives should be considered as a means of encouraging independent supply points to participate in transshipment when participation might not otherwise occur.

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Appendixes

Appendix A:

Pseudorandom Data

Data Set #	1	2	3	4	5	6
	0	2	1	3	4	4
	4	2	2	2	2	1
	2	4	3	3	1	1
	3	5	2	3	5	2
	2	2	2	4	2	2
	1	1	3	1	5	2
	1	4	3	0	1	1
	5	1	3	5	1	2
	1	5	1	5	2	5
	3	5	0	5	4	2
	1	2	0	0	2	3
	1	1	2	1	1	5
	0	3	4	2	0	3
	1	4	2	1	5	4
	5	4	1	3	1	3
	1	2	0	1	2	1
	4	0	2	4	4	2
	4	5	4	2	2	4
	3	5	2	3	1	2
	4	3	4	3	5	2
	4	2	4	3	2	5
	3	2	3	3	0	2
	3	1	4	3	1	1
	5	0	5	3	0	0
	0	4	1	2	4	3
	4	5	3	2	3	0
	5	4	3	3	4	2
	3	3	2	5	2	2
	2	1	3	2	3	4
	3	2	4	4	1	0
Runs	16	13	14	14	18	14
P-Value	.4598	.1325	.2287	.4384	.1093	.3541
Conclusion	Little or no real evidences against randomness					

Data Set #	7	8	9	10	11	12
	3	4	3	3	0	5
	4	5	2	5	1	4
	0	3	1	4	2	4
	2	5	0	4	2	3
	2	1	2	1	5	1
	1	2	3	4	3	5
	3	1	2	1	2	3
	3	2	1	2	3	0
	4	4	3	5	2	1
	0	1	0	5	3	2
	5	3	1	4	0	0
	1	3	1	5	2	1
	4	5	0	3	1	3
	1	4	3	2	1	1
	3	1	3	4	3	4
	0	5	1	3	4	2
	1	1	2	2	4	4
	1	3	1	3	3	4
	1	2	4	3	3	3
	1	1	1	4	5	2
	4	5	1	5	1	5
	0	3	2	4	3	1
	1	2	1	3	0	2
	3	2	1	3	3	4
	2	1	2	2	3	1
	3	1	3	1	2	4
	5	0	3	0	1	4
	3	2	3	3	5	1
	0	3	5	4	2	1
	2	4	4	3	1	5
Runs	16	13	15	13	15	17
P-Value	.4598	.1325	.3907	.1504	.3638	.3452
Conclusion	Little or no real evidences against randomness					

Data Set #	13	14	15	16	17	18
	5	2	2	4	5	1
	3	4	1	2	5	3
	2	2	2	3	3	4
	4	4	3	1	3	4
	2	1	3	0	1	3
	4	2	0	0	4	4
	4	1	4	5	4	2
	4	3	4	5	3	4
	2	4	2	3	5	1
	2	3	5	1	3	2
	1	1	3	1	1	3
	2	2	3	1	2	2
	1	3	1	3	3	4
	3	3	0	1	0	0
	1	2	2	3	0	3
	4	3	0	1	2	3
	4	3	0	4	4	1
	0	0	2	3	2	4
	2	2	4	4	4	1
	4	2	2	4	4	1
	0	5	2	0	3	2
	5	2	0	1	4	2
	5	3	1	0	4	2
	5	0	1	1	5	4
	2	2	4	2	5	2
	3	0	1	0	5	5
	1	4	4	5	1	2
	2	2	1	3	4	1
	3	0	1	4	5	2
	4	0	4	4	1	3
Runs	17	17	14	13	14	18
P-Value	.3452	.2675	.3541	.1325	.2287	.2202
Conclusion	Little or no real evidences against randomness					

Data Set #	19	20	21	22	23	24
	4	3	1	5	2	0
	1	4	4	1	1	1
	1	1	1	3	3	4
	2	4	2	3	3	0
	4	2	4	0	4	4
	4	5	2	1	1	2
	5	4	1	4	1	4
	1	2	3	1	4	0
	2	2	2	2	4	4
	1	0	5	3	3	4
	1	2	5	2	5	3
	1	4	1	1	3	0
	2	0	2	1	4	1
	5	2	0	4	2	3
	4	2	4	0	4	0
	4	1	2	5	2	1
	2	0	2	3	3	1
	4	5	1	0	2	2
	3	1	3	1	1	2
	0	5	1	0	5	0
	4	4	4	2	2	1
	2	5	2	2	1	0
	5	1	2	3	2	2
	1	2	1	2	3	1
	3	3	1	3	4	1
	1	1	2	2	5	0
	4	2	1	4	3	0
	0	5	2	3	4	5
	1	0	1	3	2	3
	3	3	5	5	2	3
Runs	17	17	16	17	13	14
P-Value	.3452	.3158	.1425	.3452	.1504	.2352
Conclusion	Little or no real evidences against randomness					

Data Set #	25	26	27	28	29	30
	3	2	0	0	2	2
	2	1	1	4	1	2
	1	3	1	2	2	4
	1	1	3	0	0	5
	0	1	2	1	4	0
	5	5	2	3	2	1
	2	3	2	1	2	3
	0	4	2	2	3	2
	0	2	5	2	2	1
	2	2	4	0	2	5
	4	1	5	1	2	3
	2	3	5	1	3	0
	3	4	4	5	1	5
	5	3	1	1	5	4
	3	2	1	3	3	4
	1	0	2	3	4	2
	1	0	1	3	4	2
	2	2	3	2	1	1
	5	3	5	1	4	3
	2	1	1	3	3	2
	3	2	4	1	4	3
	1	4	2	1	2	3
	5	4	5	1	2	0
	3	2	4	1	5	2
	3	2	2	1	1	1
	3	1	3	1	2	0
	4	5	2	0	2	1
	3	1	2	2	5	2
	1	2	3	3	4	0
	1	5	3	2	2	1
Runs	14	14	14	14	15	13
P-Value	.2352	.2937	.2352	.2352	.3907	.2190
Conclusion	Little or no real evidences against randomness					

Data Set #	31	32	33	34	35	36
	2	5	0	4	0	2
	2	3	2	4	5	4
	5	2	4	1	3	1
	1	3	1	3	2	1
	3	1	1	0	3	2
	1	4	0	4	0	0
	5	2	2	5	3	2
	0	4	1	3	4	2
	0	3	4	0	1	2
	2	0	2	0	2	1
	1	4	5	2	2	3
	2	2	4	4	3	4
	4	2	2	5	4	2
	2	2	0	2	5	2
	3	3	2	2	1	5
	0	1	4	2	0	4
	1	0	4	5	3	2
	2	2	4	3	3	3
	4	2	2	4	4	5
	4	5	2	5	5	2
	2	4	0	0	1	4
	1	4	2	3	0	0
	4	5	5	3	2	3
	4	3	1	4	0	4
	1	1	1	4	3	2
	2	0	1	5	3	5
	0	1	1	1	1	4
	2	1	3	4	0	3
	1	0	2	1	3	4
	3	2	3	2	3	3
Runs	16	14	14	14	14	14
P-Value	.2420	.2558	.4443	.2937	.2352	.2287
Conclusion	Little or no real evidences against randomness					

Data Set #	37	38	39
	3	1	4
	0	4	3
	2	3	2
	0	4	3
	3	4	5
	4	0	1
	1	2	3
	2	5	1
	0	2	3
	0	5	1
	0	2	3
	3	1	2
	2	4	3
	3	2	1
	4	4	2
	3	0	5
	4	4	4
	1	3	2
	5	4	2
	2	4	1
	4	3	1
	5	5	0
	1	1	4
	3	1	2
	4	2	0
	4	0	1
	3	0	2
	0	5	4
	0	3	2
	4	2	1
Runs	15	15	18
P-Value	.3638	.3638	.1567
Conclusion	Little or no real evidences against randomness		