This is to certify that the

dissertation entitled

THE IMPACT OF ALTERNATIVE INVENTORY MANAGEMENT POLICY ON DISTRIBUTION MANAGEMENT PERFORMANCE UNDER CHANGING MANUFACTURING SUPPLY CONDITIONS

presented by

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has been accepted towards fulfillment of the requirements for

Ph.D. degree in Management Science

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Date 1/28/87

THE IMPACT OF ALTERNATIVE INVENTORY MANAGEMENT POLICY ON DISTRIBUTION MANAGEMENT PERFORMANCE UNDER CHANGING MANUFACTURING SUPPLY CONDITIONS

by

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A DISSERTATION

Submitted to
Michigan State University
in Partial Fullfilment of the Requirement
for the degree of

DOCTOR OF PHILOSOPHY

Department of Management

1987

ABSTRACT

THE IMPACT OF ALTERNATIVE INVENTORY MANAGEMENT POLICY ON DISTRIBUTION MANAGEMENT PERFORMANCE UNDER CHANGING MANUFACTURING SUPPLY CONDITIONS

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This research evaluated the effects of production scheduling policy, inventory management approach and safety stock positioning policy on the distribution performance of a one supplier, two wholesalers channel system, under two conditions of environmental uncertainties. Results from dynamic simulations of a tightly-coupled production-distribution system indicated that "chase" master scheduling strategy contributed to significantly better distribution performance than "levelled" strategy. There was strong evidence for better inventory and service performance in system managed by "Push Inventory System", than those managed by "Pull System". However, Push System exhibited high service performance with relatively low inventory level only under conditions of low environmental uncertainties. The research further suggested that positioning safety stock at lower echelon facility under a limited inventory supply condition would not be beneficial toward improving distribution service performance.

ACKNOWLEDGEMENTS

I am in debt to Dr. Ram Narasimhan, for his patient guidance, and constructive criticisms throughout the dissertation research. His skillful supervision inspired extra depths into the research study, and his challenges for excellency improved the overall quality of the research. My deepest appreciation goes to Dr. Richard Gonzalez, and Dr. David Closs for commenting on the many revisions of the manuscript, and contributing their expert knowledge toward the research design. The reading quality of the manuscript has been greatly enhanced through the editorial assistance of Dr. Robert Smith of Alma College, although I am solely responsible for the final manuscript. The support and encouragement of my colleagues at Central Michigan University is greatly appreciated. I am especially thankful to Dr. Shahabuddin for relieving me from committee responsibilities, and the generous office support for preparing manuscript. It is beyond expression the support I received from my wife, Irene, who also prepared a great portion of the manuscript. Finally, I thank my parents for the opportunity to pursue my studies, and for their blessings of a faith in the God who inspired the Bible, who blessed and supported me through many difficult periods during the doctoral program.

TABLE OF CONTENTS

Chapter

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.0 THE LAST FRONTIER FOR PROFIT

During the last few decades, firms in the United States have experienced several major shifts in managerial emphasis: from production efficiency, to periods of market expansion in the sixties, followed by an era stressing financial return in the seventies (Pohl, 1973). The eighties is dominated by the systems view, with much effort toward integration of functional operations, especially in the logistics management of product movements.

As early as in the 1950s, Peter Drucker prophesied logistics as the "Last Frontier for Profits" (Vollman, Berry and Whybark, 1984). It has taken the next three decades for management to recognize the potential productivity improvement through logistics management. Deregulation of rail, truck, and air transportations in the early 1980s have fueled innovative transportation management, which together with high technology, and new concepts in inventory management, have made managing logistics profitable. During the period between 1978 to 1983, an industrial survey (Morehouse, 1983) reported an average 12.6% improvement in distribution productivity, with a projected further improvement opportunity of 12.5%. Considering the 1983 logistics bill in the U. S. at approximately $650 billion, the opportunity for productivity improvement exceeds $80 billion per year.

Inventory management is a logistics activity that has been accounting for as much as 11.5% productivity improvement during the 1978-1983 period. Under deregulated environment, and with the increasing acceptance of just-in-time concepts in production and procurement, inventory managers face a challenge in selecting appropriate tools for managing inventory flow through tightly coupled distribution channel. This study investigates the relative performance of inventory policies, for inventory management across the functional interface of production and distribution.

1.1 FRONTIERS IN INVENTORY RESEARCH

Inventory management has been a major concern of both researchers and practitioners for the last three decades. Despite a rich body of inventory theories and practical guidelines, and the recent introduction of computerized inventory planning systems, there are recurring needs for improving existing inventory management techniques. Two possible explanations for the ongoing needs for inventory research are the changing roles of the inventory function, and the increasing complexity of business environments. Existing inventory theories become insufficient for addressing the larger varieties of inventory management problems.

For many years, the inventory function has been treated as a cost center, with inventory theories developed through cost minimizing models for simple inventory systems, with single facility, single item, and often under deterministic environments. With changing organizational structures of firms, the responsibility of inventory management is divided among multiple functional areas. Consequently, inventory managers must also address other managerial concerns such as customer service, product distribution, and product quality (McCollum 1981; Buffa, 1979).

Recently, multiechelon, multi-item inventory distribution systems, operating under uncertain environments, present increased complexity in inventory management. Although researchers have started to address the managerial concerns for multiechelon inventory management, progress is slow (Schwartz,1980). Moreover, uncertainties, and threats of discontinuity of materials and inventory supplies, create additional difficulties for inventory managers.

Under complex business environments, top management is giving increasing attention to two strategic issues of inventory management - customer service, and inventory investment. Highly competitive market conditions require high inventory levels for supporting competitive service goals. Economically, high inventory carrying costs and uncertain economic conditions make it undesirable to maintain high levels of inventory (Morehouse et.al, 1983). The broader economic tradeoff between service and inventory investment, at the top management level, is not adequately investigated (Wagner,1980).

While much research in inventory management has been directed at the improvement of inventory management within individual functional areas, with emphasis on techniques and models that optimize the operation of individual functional areas, elements of functional interactions and dynamic changes are often omitted from these models. Moreover, managers find it difficult to apply optimizing models to broader inventory management issues such as managerial actions for changing demand patterns under fluctuating economic conditions, changing transportation and communication services, shortened product life cycles, and complex networks of inventory systems (Smith, 1982).

Toward the investigation of functional interactions, researchers and senior management have begun to explore integrated management of multiple functional areas through joint planning, educational efforts, and goal setting

(Bowersox et.al, 1984). However, integrated management of inventory in physical distribution systems, especially for non-vertically integrated distribution systems, is not well investigated.

On the other hand, rapidly changing environments present an urgent need for addressing the problem of managing dynamic systems (Smith,1982). To the distribution inventory manager, this means that he not only acquires a sound understanding of basic management techniques, but also be equipped for managing multiechelon inventory systems, under dynamic environments. Hence, functional interactions and their effects on the effectiveness of inventory management, as well as the various inventory objectives, especially the broader economic issues, should be considered.

Through the interaction of independent inventory policies adopted by two channel members in a channel of distribution, this study investigates effects of production policies, inventory management approaches, safety stock policies and information quality, on distribution inventory performance, in terms of both customer service and inventory investment.

The remainder sections of this chapter present the definitions of special terms and considerations in distribution management, the research objectives, research procedures, and potential contributions of the research.

1.2 INVENTORY MANAGEMENT IN LOGISTICS DISTRIBUTION

Logistics refers to "the process of planning, implementing and controlling the efficient, cost effective flow and storage of raw materials, in-process inventory, finished goods, and related information from point of origin to point of consumption for the purpose of conforming to customer requirements" (CLM, 1985). Flow of items is facilitated through channels of distribution.

A channel of distribution involves "numerous organizational units, either internal or external to the manufacturer, which perform the functions involved in product marketing. A channel member is any individual organizational unit which performs one or more of the marketing functions" (Lambert,1978).

Inventory management under distribution environments is complicated by the numerous activities and channel members that can influence product flows, associated costs, and effectiveness of inventory policies. Futhermore, multiechelon inventory systems are common, and distribution of various forms of inventories - raw materials, components, and finished goods, requires different inventory management objectives and policies.

Broadly speaking, there are two major distribution inventory management approaches - decentralized inventory management system, often referred to as the "Pull Distribution System", and centralized inventory management system, also known as the "Push Distribution System". Although there have been reports of hybrid Pull-Push System (Dixon, 1985), such systems tend to employ "Pull Systems" and "Push Systems" for management of separate products under different segments of a large distribution network. Therefore, hybrid Pull-Push Systems represent the integrated application of the Pull System and the Push System, rather than a third inventory management approach.

The terms "Pull System" and "Push System" may cause confusion for some readers because of their reported usage in several contexts. A discussion of the various definitions of the terms may be helpful.

According to the APICS dictionary (Wallace, 1984), authors use the terms "Pull System" and "Push System" in at least three different ways: for applications in production, materials management, and distribution, respectively.

Under production environment, a Pull System refers to "the production of items only as demanded for use, or to replace those taken for use" (Wallace, 1984). A production system that allows its production activities to be driven by demands - either actual customer orders, forecasted or anticipated demand, or actual usage, is qualified as a Pull System. On the other hand, a Push System schedules its production activities according to a predetermined master plan - a detailed statement of the production plan, developed according to forecasting information and business strategy. Typically, a make-to-order production environment is a Pull System. Both the Pull System and the Push System can be found in make-to-stock environment.

Secondly, the terms "Pull system" and "Push system" are used in the context of materials control. In materials management, a Pull System refers to a system that withdraws inventory as demanded by the using operations. The Pull System issues materials only after receipt of a signal from the user. On the other hand, a Push System issues materials according to a predefined schedule of needs.

Lastly, "Pull" and "Push" are used in a distribution context. The "Pull Distribution System" gets its name from multiple independent warehouses reaching out and drawing replenishment stocks from a central stock, by issuing independent replenishment orders. Since inventory movements are triggered by customer demands that deplete inventory stocks at lower echelon locations, inventories are said to be pulled through the channel (Whybark and Williams, 1976). The central facility plays a passive role of filling replenishment orders according to predetermined priorities.

The "Push Distribution System", characterized by the central production facility playing an active role in positioning available inventory at remote warehouses (Shawchuk, 1985), according to anticipated customer demands, and a detailed plan of needs submitted to the central facility. Since inventories are directed to remote facilities, before the arrival of customer orders, according to a master plan, inventories are seen as being pushed to the customers.

Despite the potential confusion, this report will apply the definitions under the distribution context to all future reference of the terms "Pull System" and "Push System", for consistency with existing reference of the terms in distribution literatures.

Regardless of the definitions, the Pull Distribution System and the Push Distribution System differ more than merely decentralized versus centralized decision making. In order to better understand the two inventory management approaches, it is helpful to first review the characteristics of distribution inventory problems. Then, a systematic comparison of the two inventory management approaches can be more meaningful.

Distribution inventory management involves managing inventories across spatially and geographically separated physical facilities. The additional locational dimension presents several management problems - level of decision making, communication, information quality, coordination, and time delays.

The distribution channel structure and the organizational structure determine the level of inventory decision making. In a channel where lower echelon facilities are operated by independent organization units external to the manufacturing organization, the channel member with the higher economic leverage has potentially stronger voice toward inventory decisions. Manufacturing organization that is larger, and economically stronger relative to the lower echelon members, is in a favorable position to exercise centralized inventory decisions. If the reverse is true, then decentralized inventory decision may be expected. For example, companies like General Motor and Ford are the major advocates in encouraging their suppliers to support the just-in-time inventory practice.

For a vertically integrated distribution channel, centralized inventory decisions are often associated with central control of channel operations; and decentralized inventory decisions are characteristics of organizational structure that encourages autonomy of individual organization units.

The Pull System is common in channels of distribution with multiple independent channel members, or independent organizational units. Although localized independent replenishment decisions may optimize total cost for local operations, optimization at the subsystem level may sacrifice optimal effectiveness for the whole distribution system. Some have criticized the Pull System for its uneven distribution of inventory among the distribution facilities, resulting in ineffective inventory support for service goals.

The Push System centrally plans and allocates inventory to various distribution facilities according to anticipated needs. However, effectiveness of the system is dependent on information quality and the effective deployment of limited supply of inventory.

Pull Systems and Push Systems also differ in their communication linkages. The inventory management communication linkage between echelon levels consists of two types of information: forecast information and order information. "Forecast information" refers to demand forecast from distribution facilities to the central production facility, and a reverse flow of forecast for supply availability, or capacity forecast, to the distribution facilities. Order information includes replenishment orders issued by the distribution facilities, as well as order status information provided by production facilities.

Under a Pull System, distribution facilities communicate with central facility through infrequent aggregated forecast information and independent replenishment orders, which provide very poor information for detecting and coordinating the actual requirements at various distribution facilities. On the other hand, a Push System relies on accurate, timely requirement forecasts, rather than replenishment orders, for inventory replenishment actions. Formal communication linkage established in the Push System also facilitates order status reports, and order adjustments.

Effective communication depends on the quality of information, which is subjected to data processing and decision filtering when transmitted through multiple levels of management. Since a Pull System communicated through replenishment orders, demand information becomes inseparable from order information reflecting changes in safety stock policy, replenishment decision rule, cash flow position, and purchasing strategy. Thus, the order information may mislead when used for planning production activities. A Push System distinguishes demand forecast from other information flows, and therefore able to utilize more information for production planning.

For distribution systems, coordination of activities among remote distribution facilities is difficult because of the distance, and variety of demand patterns at various geographical locations. Coordination is especially difficult under a Pull System with different replenishment decision rules among the distribution facilities. For example, one distribution facility may decide to issue an order to increase its safety stock inventory, while another facility may issue orders after inventory stockout. When the central facility attempts to fill the arriving orders, the priority of those orders on a need basis cannot be determined. Moreover, uncoordinated activities such as promotional events, often lead to lumpy demand, causing additional confusion and service deterioration. Through centralized inventory planning, a Push System acquires better visibility on actual needs of various distribution facilities, and therefore more capable of responding to special inventory requirements.

Lastly, distribution systems often encounter long delays in both information and materials flows. When multiple channel members are involved in a channel of distribution, even longer delays are anticipated for interorganizational activities, compared to intra-organization activities. Example of information and material flow barriers include goal conflicts, policy conflicts, and incoherence of operations (Jones and Riley, 1984).

Three groups of time delays contribute to the time delays in distribution inventory replenishment. First, order communication delays account for time elasped from order preparation at a distribution facility, order transmission, until complete processing of order at the production facility. The second group of time delays relates to inventory preparation activities such as inventory production, order picking, and packaging.

Lastly, order shipment delays account for activities including inventory loading, shipment consolidation, transportation, and inventory receiving at distribution facility.

Generally speaking, enhanced communication linkages permit reduction of the order cycle for the Push System. Formal communication channels of Push Systems assist coordination of distribution activities and production activities, thus reducing inventory preparation time. Moreover, forward looking capability of the Push System allows advance booking of carriers, and coordination of receiving activities at distribution facilities. All these potentially shorten shipment delays. On the other hand, Pull Systems have limited control over replenishment delays because of poor communication, as well as weak coordination among production and distribution activities.

Another major difference between Pull and Push systems is in management tools. Pull Systems employ analytical inventory models, mostly single echelon derivatives of the economic order quantity (EOQ) model, for finding the best timing and quantity of inventory to move through a channel of distribution. While Push systems integrate analytical techniques and information systems in computerized inventory planning systems, such as Distributing Requirement Planning systems, the emphasis is on system responsiveness rather than system optimality.

From an implementation point of view, a Pull System requires relatively low level of information, and is easy and inexpensive to implement, although it may fail to capture realism because of restrictive assumptions. On the other hand, the Push System offers potential inventory savings and improved service, but it requires substantial initial capital investment, and subsequent data processing cost, in addition to timely and accurate information.

Although there are numerous studies on both the Pull and the Push inventory approaches under different environments, the comparative performance of the two approaches is not well understood (Doolan, 1984). There is no report of a systematic comparison of a Pull System and a Push System under controlled experimental condition, with controlled measures of resource availability, and associated performance.

Currently, Pull Systems still prevail in many distribution inventory systems (Detscher, 1985). However, Pull Systems equipped with analytical models are somewhat limited at capturing dynamic changes in inventory systems (Closs, 1978). Moreover, single echelon inventory models are inadequate for multiechelon inventory problems such as ill-behaved demand patterns, achievement of system optimality , and interactive effects of inventory shortage at various echelon levels (Schwarz, 1981). Some researchers continue to develop analytical models for well defined inventory problems, regardless of low acceptance of such models among the practitioners (House, 1983).

Recognized the drawbacks of the Pull System, some researchers, and software vendors promote computer based inventory planning models using "Push" replenishment logic as the solution to inventory management problems. However, high investment costs, required organizational changes, and strict requirements for accurate forecast information, thwart widespread implementation. Time and further research may demonstrate their potential (Wight,1982).

Beside the promotional force for Push Distribution System, recent emergence of the just-in-time concepts is another major force that may significantly affect the practice in distribution inventory management. Since just-in-time concepts advocate the removal of redundant inventory, continued elimination of inventory would eventually expose distribution activities to changes in production activities such as alternative production scheduling policies. It is especially desirable to understand the interaction between production activities and distribution activities, when the production plan fully utilizes planned production capacity, which is inflexible over the short run. In addition, some lower echelon channel members are concerned about the shifting of inventory to them, when upper echelon members adopt just-in-time production (Feldman, 1984).

The Literature reveals little information concerning the interaction of inventory policies between manufacturing and distribution functions, especially for independent channel members in a distribution channel. With recent changes in the manufacturing sector, the implication of manufacturing policy changes should be understood.

1.3 RESEARCH OBJECTIVES

The primary research objective of this study is to identify policy elements at the production-distribution interface, that significantly affect performance of distribution inventory systems. Specifically, this study evaluates distribution inventory policies, production scheduling policies, safety stock policies, and impact of environmental uncertainties on performance of a tightly coupled production-distribution system.

Despite the recent attention devoted to Push System, it is still questionable whether it works well for all circumstances (Dixon, 1985; Davis, 1985). One of the fundamental questions not fully answered is, in what way does the Push System, in the long run, perform better than Pull System, from a system point of view, and under what environmental conditions? Specifically, it is desirable to understand whether it is (1) computerized planning tools, (2) information quality, (3) innovative distribution techniques, (4) better discipline and management committment, or (5) central decision making that contributes to the effectiveness of the Push System. Since computerization and management involvement are not directly related to inventory policy tradeoffs, the focus will be on the other three areas.

One of the fundamental requirements for successful implementation of Push System is accurate forecast information. The quality of forecast information is affected by the forecastability of the forecast item, the suitability of the forecasting technique, and the timeliness of the forecast information. Only the forecastability of item will be addressed in this research. Together with consideration of leadtime variability, a research question is raised concerning the effect of environmental uncertainties on distribution performance. The specific research question is whether effect of environmental uncertainties on performance of distribution systems, varies significantly with implementation of different distribution inventory management approaches. If effect of environmental uncertainties is not dependent on inventory policy, then it should be addressed as an issue independent of inventory management systems.

When information fails to remove uncertainties, safety stock can be implemented for protection against environmental uncertainties. However, under influence of just-in-time concept, safety stock would be limited, if not totally eliminated. Consequently one has to decide whether a limited supply of safety stock is more effectively positioned at the lower echelon wholesaler facilities, or retained at the upper echelon level. Conceptually safety stock is more effective at lower echelon facility because of proximity to customer, and its protection against both demand and lead time uncertainties (Cook, 1980; Sawchuk, 1985). However, it is also known that lumpy replenishment orders from lower echelon facilities under the Pull System create many inventory problems at central facility. Therefore the next research question is to investigate whether safety stock positioning strategies interacts with distribution inventory approaches.

Push Systems have been shown to perform better than Pull Systems under conditions of demand and lead time uncertainties (Closs and Law, 1983). The third research question investigates whether Push Systems perform better than Pull Systems under broader circumstance, especially under various supply conditions. Previous research indicated that dissimilar values of some decision factors common to both the Pull System and the Push System partially affect the inventory system performance (Closs and Law, 1983). Examples are order quantity and review period. This study controls the impacts of such common decision factors by setting them to comparable levels for both the Pull System and the Push System, and compares the two systems under controlled environments.

The last research question concerns testing whether production scheduling policy is a significant factor to be considered in design of distribution inventory management system. Many distribution inventory models fail to consider problems of supply limitation. At best, the production process is represented by simple production rate functions. This research considers a capacitated, multi-product, multi-process production environment, and investigates whether production scheduling policy, and supplier safety stock policy would impact on distribution inventory performance. The study considers two master production scheduling approaches: levelling strategy, and chase strategy (Vollmann, 1984).

1.4 RESEARCH PROCEDURE

This research study requires a controllable business environment under which performance of the Pull System could be compared against that of the Push System. Since neither actual distribution system nor survey study could provide the controlled environment desired, a simulation experiment was performed. All the desirable system characteristics were first captured in a conceptual model that captured the simplest possible system structure. A computer model was developed and validated with realistic parameters. A factorial experiment was conducted with the simulation model, with data collected from 14 replications of sixteen treatments from combinations of four factor levels. The factors included distribution inventory management approaches, production scheduling strategies, levels of environmental uncertainties, and safety stock positioning strategies.

Average quantity fill-rate at the distribution facilities, and the corresponding average inventory levels were recorded as performance measures while the simulated system was in steady state.

The statistical technique of multivariate analysis of variance was employed to analyze collected data for hypothesis testing. Ranking of performance of inventory management systems was conducted through multiple comparison procedures. Lastly, graphical illustration of the empirical relationships between inventory investment and service performance are presented.

1.5 POTENTIAL CONTRIBUTIONS

Recent developments in inventory research have produced a large assortment of inventory management tools, each proclaiming superior performance characteristics. Bewildered inventory managers could easily find themselves spending as much time evaulating and managing the management tool, as the time devoted to managing the basic inventory function. Inventory research could contribute to the objective evaluation of inventory systems by identifying the key factors that account for the effectiveness of inventory management systems.

This research investigates the relative importance of fundamental decision factors toward the effectiveness of distribution inventory management. Results of this research provide fundamental understanding in the design of effective inventory management system for specific applications.

Systematic comparison of the performance of inventory management approaches, in broader environments, provides additional insight for objective evaluation of inventory management tools. The ability to put the correct tool into the hands of managers could improve the creditability of inventory researchers, and facilitate the effort of educating practitioners in scientific management practices.

Since this study addresses the production - distribution interface, information from this research could assist the design of functional interface. Research insight on the interaction of independent inventory policies between channel members, could aid management's efforts to coordinate channel activities in distribution systems.

Moreover, many firms can benefit from providing higher customer service levels to key accounts than for other customers (Lalonde and Lloyd, 1983; Dixon, 1985). A better understanding of the inventory and service tradeoff of different inventory policies can assist customer service decisions.

While this research addresses several other problems such as impacts of safety stock policy, forecasting accuracy, and potential saving through economies of scale, time and resources restrict the in-depth analysis of these problem areas.

1.6 ORGANIZATION OF CHAPTERS

Chapter two presents a review of the literature of selected inventory topics, while chapter three discusses the conceptual model representing the selected inventory system. The conceptual model serves the dual purpose of providing a summary of the various activities included in the simulation study, as well as a quick reference for comparison with other research works.

Chapter four describes the research methodology and hypotheses, followed by research results and analysis in Chapter Five. The concluding remarks in Chapter Six summarize the overall findings, and translate the current research findings into managerial guidelines and future research suggestions.

CHAPTER II

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter presents a literature review on various factors associated with distribution inventory management, and highlights major findings in distribution inventory research. The chapter is organized into three sections: in the first section the reader will find a survey of inventory management problems in physical distribution; in the second section a discussion of major scientific techniques and models employed in distribution inventory analysis, with discussion limited to major research works in representative problem areas; while the last section reviews simulation studies for multi-echelon distribution inventory systems.

2.1 DISTRIBUTION INVENTORY MANAGEMENT PROBLEMS

Basic characteristics of distribution inventory problems have been discussed in Chapter One. This section reviews management considerations associated with distribution inventory problems, with emphasis on management implications of individual problem areas. Selected literature survey on special distribution inventory management problems provides justification for the research study. Furthermore, surveys on elements of inventory policy, and performance measurements of inventory policy are presented to support the conceptual model described in Chapter Three, and the detail model structures discussed in Chapter Four.

2.1.1 Distribution Inventory Management Problems

Several distribution inventory management problems deserve special considerations. First, multi-echelon inventory systems across multiple independent firms are common in distribution network. The second problem is the selection of management approach. Here a decision is difficult because of the large variety of system structures, and highly uncertain environments. Moreover, the heavy emphasis on customer service, in addition to cost measurement, creates many difficulties in performance evaluation. Lastly, inventory logistics are severely affected by environmental uncertainties.

In a typical distribution environment, product flow from the manufacturer to the customer involves numerous activities performed by many organizational units. Thus, inventory management must be coordinated throughout the individual activity of channel members.

However, multi-echelon inventory research has dealt mainly with the management problems of the vertically integrated echelon structure of a single channel member. The knowledge on the interaction of independent inventory management decisions by independent channel members is limited (NCPDM, 1978).

Although researchers recognize that one of the key factors for future success is to adopt a total pipeline view of materials management, from the supply source all the way to the customer point of use, organizations dealing with a segment of the distribution pipeline still fail to step across functional boundaries and see how other segments of the pipeline operate (Burns, 1985).

Moreover, researchers often assume an infinite supply source, and many inventory replenishment and allocation rules grow out of the assumption that the suppliers can always provide inventory upon request (Martin, 1983).

Recent changes in manufacturing environments deserve closer attention. Many manufacturers have taken steps to reduce inventories of all forms under pressure from high interest rates, shortened product life cycle, and a fresh memory of overstock of inventory during an economic downturn. The introduction of just-in-time philosophy, when implemented, may affect the ability of manufacturer to respond to sudden request for inventory (Hall,1983). The available literature reveals very little of the impact of such changes in the manufacturing industries, on the distribution function. A major focus of the current study is to investigate the interaction of production policies and distribution inventory policy on distribution inventory performance.

Inventory performance is affected by inventory replenishment approach. While many writers agree that Material Requirement Planning system seems most suitable for manufacturing environments (Martin, 1983; Doolan, 1983), one finds diverse viewpoints on the appropriate inventory replenishment approach for distribution environments. Despite the volume of research addressing the Pull System and the Push System (Peterson and Silver 1979, Martin 1983, Schwartz 1981, Clark 1972, Krajewski et al. 1983, Orlicky 1976, Tersine 1982, Vollmann et al. 1984), a recent survey indicates that still very little is known about the incremental inventory requirement, if a Pull System is utilized instead of a Push System (Wagner 1980).

Under active promotion by vendors of computer systems, a common pitfall is choosing a Push System based solely on the leading edge of computer based inventory planning system, while neglecting the relative effectiveness between the Push system and the Pull System, for the specific application (Doolan, 1983).

A systematic comparison of a Pull System and a Push System under controlled environments can provide objective answers to the relative effectiveness of the two management approaches for specific environments.

The third management problem is the much greater emphasis on customer service in distribution inventory management (Martin,1983). Recent trend indicate that many leading firms now emphasize customer service as an important goal of logistics planning (Hanna et al., Morehouse et al., Majeczky et al., 1983). Management is placing increasing emphasis on developing a logistical operation capable of attaining required service performance, at the lowest possible cost (Bowersox, 1978). This implies that the service goal set by management should be attainable within cost and budget constraints, and that a least cost system is desirable for implementation only if it supports the service goal. Therefore, inventory management analysis should be capable of simultaneously measuring the service performance, and cost performance of a given inventory policy.

The dilemma of establishing simultaneous measures is that service performance is approximately inversely dependent on inventory performance. A high service level usually requires substantial increase in inventory support (Whybark and Williams, 1976). Currently, studies do not reveal the inventory investment tradeoff between different service measures for a wide variety of inventory replenishment models (Wagner,1980). Through better understanding of the relationship between inventory investment and customer service, an effectively designed inventory management system can significantly improve service preformance without excessive inventory investment.

Finally, spatially dispersed inventory stocking locations in a distribution system present special inventory management problems. Under an uncertain environment, safety stock inventories at multiple stocking points becomes necessary in many situations. Both the quantity and the positioning of the safety stock have direct impact on both inventory and service performance (Cook, 1980). Coordination of safety stocks between independent members at multiple echelon levels is important toward the effectiveness of the entire distribution channel. Thus it is desirable to understand the relationships of independent safety stock policies among independent channel members.

Another important factor is the longer, and relatively uncertain lead time for inventory transfer between distribution locations. Uncertain lead time, coupled with poor demand forecast (House,1983), accounts for much of the difficulties in distribution inventory management. Since uncertainty is unavoidable under distribution environments, performance of inventory management approach should be assessed under uncertain environments.

2.1.2 Inventory Policy

The recent introduction of numerous techniques, tools, and philosophy in inventory has created much interest, but comparatively few successful results. Although some of the proposals are conceptually appealing, their suitability for application under broader circumstances is questionable (Dixon, 1985). The availability of a large collection of inventory management tools makes the inventory management decision more difficult, unless evaluation guidelines are available to compare the various tools. This section reviews the fundamental elements of inventory policies, from which the performance characteristics of various inventory management tools can be better understood.

Distribution inventory policy determines the timing and quantity of inventory to be transferred between locations, and the amount of inventory to be positioned at each location. Each policy can be seen as a combination of decision factors that individually, or collectively contribute to the effectiveness of the policy. Since some decision factors are common among inventory policies, either under a Pull System or a Push System, it is desirable to understand how these decision factors influence the effectiveness of inventory policies.

The timing of inventory movement is controlled by two factors. The first factor is the review frequency. A continuous review rule checks the inventory level whenever inventory is depleted by demand. An inventory policy with continuous review is responsive to changes in inventory levels. The periodic rule adopts periodic inventory reviews. Short review periods decrease inventory level and improves system responsiveness (Gross and Soriano, 1969), but at the cost of higher risk of stockout, and forgoing scale economies (Closs and Law, 1983).

The second factor is the reorder level. Inventory movement is triggered only if the inventory position falls below the reorder level when inventory is reviewed.

Replenishment quantity is determined by several factors. The first and most important factor, demand forecast, is either a static average value, or dynamically updated when reviewing inventory. An inventory policy adopting dynamic demand forecast adapts to environmental changes. Accuracy of forecast information has significant impacts on the performance of inventory policies.

Cost tradeoff analysis determines the optimal order quantity. Cost elements will be discussed in a later section concerning performance criteria. Other factors influencing order quantity include batch size requirements, strategic considerations, limited inventory supply, and promotional activities.

Order quantity can be fixed, or variable through time, with different cost and service implications. A large order quantity is penalized on carrying cost, but enhance service performance as well as scale economies (Closs and Law, 1983).

The allowable inventory movements between locations is another consideration. Most inventory policies restrict inventory transfer to between echelon levels, and disallow inventory transshipments among locations in the same echelon level. Some policies allow inventory transfer between any echelon levels, for example, between factory and distribution centers without going through regional warehouse. Other policies restrict inventory transfer to follow a hierarchial structure of echelon levels. Flexibility in inventory transfers often lead to higher system cost (Gould, 1984).

Safety stock decision correlates with the inventory decision. In a multiechelon environment, management must consider safety stock level, as well as the location of safety stock deployment. Though some suggest that positioning safety stock at lower echelon level provides more effective service support (Cook, 1980), the current literature reveals little on the role of safety stock in multifunctional, multi-organizational, and multiechelon distribution system.

There are numerous safety stock rules, including fixed quantity, days of supply, stock probability, and hybrid rules of the above.

Lastly, the inventory policy can adopt a centralized control of inventory, such as the case for Push System. Alternatively, inventory replenishment control can be decentralized, and inventory movement is triggered by actual demand, as for the Pull System.

2.1.3 Performance Measurement

A majority of the inventory models adopt a cost minimizing performance criterion. The numerous cost elements include capital cost, tax and insurance, storage costs, inventory risk costs, order cost, transportation costs, warehousing costs, stockout costs, production lot quantity costs, volume discounts, and many others (Lambert and Sterling,1984). However, most of the costs incurred in carrying inventory are difficult to assess and can seldom be determined directly from accounting records (Peterson and Silver,1979). The calculation of inventory costs, at best a rough guess, have not been accurately determined and in many cases the figures used bear little relationship to economic reality (Lambert and Sterling,1984).

While there are some inventory models that use profit maximization as the performance criterion (Ballou, 1965), even fewer models treat customer service as a performance criterion. However, one of the concerns in top level economic analysis and strategic decision is the tradeoff between inventory investment, and the strategic provision of customer service. Inventory models are seldom measured by the ability to meet strategic priorities (Buffa, 1979).

Of the numerous means of measuring customer service, two most common service criteria are product availability, and short order cycle time (Lalonde and Zinszer, 1976; Doolan,1983). Both of these service measures are closely associated with inventory support, and therefore suitable for this study.

2.2 MODELS AND TECHNIQUES FOR MULTIECHELON INVENTORY ANALYSIS

Since the survey conducted by Clark (1972) on multi-echelon inventory theory, numerous inventory models and techniques have been proposed. In order to present the relevant literature in a manageble manner, a classification scheme would be helpful. Table 1 presents such a classification scheme, which is constructed from the schemes presented by Silver (1981) and Tersine (1982), and from multiechelon problems reported in the literature (Schwarz, 1981).

Table 1: A Classification of Multiechelon Inventory Problems

CLASSIFICATION SCHEME

. Product Group	Single Item Multiple Items
. Knowledge of Future Demand	Deterministic -Constant -Variable Probabilistic -Known Distribution -Known Parameters -Unknown Parameters -Unknown Distribution Uncertain
. Nature of Supply Process	
a. Supply Source	Unlimited Supply Limited Supply
b. Lead Time	Deterministic Probabilistic
. Time Horizon	Single Period Multiperiod -Stationary process -Unstationary process
. Stockout Management	Backorder Allow Sales Loss
. Multiechelon Structure	Assembly Arborescence
. Inventory Replenishment Logic	Pull Push
. Product Characteristics	Nonreparable Product Reparable Product

This study addresses inventory management problems classified as multi-period, multiechelon with arborescent structure, multi-item, in nonreparable consumer goods distribution. Stochastic demand (with seasonal parameters) and stochastic lead time with a capacitated supply source characterize the environment. Both demand and lead time are described by known distribution pattern with known parameters. Both Pull and Push inventory replenishment logics are investigated, with safety stock employed at specific echelon level. Stockout is handled by backordering at both production level, and at distribution level.

Models with stochastic demand, time-varying parameters and multi- period time horizon are well discussed in literature (Silver,1981). However, models treating both demand and lead time simultaneously as stochastic elements are relatively few. One of the earlier studies was by Gross and Soriano (1969), who demonstrated that reducing average lead time for a single echelon replenishment system would lead to inventory reduction. Treating both demand and lead time as stochastic elements, Dirickx and Koevoets (1977) demonstrated the use of expected average cost as a performance measure for a single echelon system. Sims (1978) used a two echelon system to study the impact of forecasting techniques on multiechelon system with stochastic demand and lead time. Rosenbaum later presented a interesting and detailed analysis of the use of a heuristic algorithm developed for analyzing safety stock positioning strategy of a three-echelon system (Rosenbaum, 1980). During the same time period, Cook studied safety stock positioning strategy for a two-echelon system (Cook,1980). He suggested that a statistical approach to safety stock planning is inadequate for multiechelon systems. However, common deficiencies in the literature (cited above) are the basic assumption of unlimited inventory availability at supply source, and the restriction of the analyses to the Pull inventory replenishment approach.

Multi-echelon inventory systems have been investigated under many conditions, through optimizing mathematical models. However, implementation for such models in practice is hindered by the restrictive assumptions and massive simplification during the modeling process (House, 1983). Moreover, optimal solutions are hard to obtain for many mathematical models. There are also limitations to the level of detail that can be incorporated into optimizing mathematical models. For example, though there are numerous analytical inventory models that include constant lead time (Deuermeyer and Schwarz, 1981), there is little progress in the integration of stochastic lead time into analytical models. The major difficulty is the increase in complexity with additional variables.

However, lead time variations affect inventory system. Gross and Soriano (1969) showed that lead time reduction can significantly reduce inventory especially under high service requirements. They also concluded that sensitivity of inventory system to leadtime variation is greater than variation in demand and distribution shape. Wagenheim (1974) confirmed the findings of significance of leadtime variations on performance of a multi-echelon distribution system. Similar findings are reported by Aggerwal and Dhavale (1975).

Another common technique for analyzing multi-period inventory problem is dynamic programming. Dynamic programming is a very powerful analytical tool for single echelon system, particularly where a single product is involved. In the case of one supplier, N-customer system structure, with lead time treated as probabilistic element, simulation techniques becomes a more favorable technique for analysis (Ballou,1965).

2.3 SIMULATION OF INVENTORY SYSTEMS

Simulation analysis allows the inclusion of more system components in the modeling of complex systems. Simulation also provides a good representation for the joint replenishment of multiple products. However, even with simulation analysis, the dynamic performance of inventory policies through time is not well investigated, especially under conditions of both demand and lead time uncertainties, with limited supply of inventories.

One of the earlier simulation studies of inventory systems, by Forrester, considered a deterministic model, and demonstrated the significance of delays in information flow and physical flow (Forrester,1961). Ballou studied an inventory system with three vertically integrated firms. The simulation study considered stochastic demand and lead time, and a large array of cost factors. The concept of improved profit performance through system approach was tested and demonstrated (Ballou, 1965). Gross and Soriano(1969), Wagenheim (1974), and Aggerwal and Dhavale (1975) have all used simulation as research vehicle.

Closs (1978) incorporated production, forecasting, transportation, and demand patterns in the construction of a simulation package known as Simulated Product Sales Forecasting (SPSF). The simulator is instrumental in a series of studies concerning impacts of forecasting techniques (Sims,1978), safety stock positioning (Cook,1980), and inventory replenishment policies comparison (Closs and Law,1983).

Recently, McCollom used a simulator to experiment with restrictions on production level, and dynamic adjustment of parameters for Pull replenishment policies (McCollom,1981; McCollom and Blank,1982). The simulation environment allows probabilistic demand and lead time, with integrated distribution activities. However, Push replenishment logic has not been considered. Another recent development is the Distribution Requirement Planning (DRP) system, which permits coordination of replenishment of multiple items in multiechelon system through a "push" replenishment approach. However, the assumptions of fully integrated channel of distribution and known demand pattern, limit its application for dynamic, uncertain environments. Although some researchers have proposed managing uncertainties for the Push replenishment approach (Whybark and Williams, 1976), most do not document performance of that system under stochastic demand and lead time.

There are two other major areas of simulation research in multi-echelon inventory analysis: the representation of demand pattern, and the forecast of future demands.

Several common distribution functions for demand representation are Poisson, Exponential, and Normal distributions. These distributions have been cited to be good representations for demands at levels of retail, wholesale, and factory, respectively (Buffa and Miller 1979, Buchan and Koenigsberg 1963). Application of Poisson distribution is limited to a fairly narrow range of low average demand value (Buchan and Koerigsberg 1963). Normal distribution has an undesirable negative tail. A less well known distribution function, the Gamma distribution, gives a wide range of shapes that changes with the mean demand of items, and is defined only for non-negative values (Burgin,1975). Exponential distribution is a special case of Gamma distribution.

Forecast accuracy is one of the major considerations in inventory management. Many inventory models assume perfect forecast when demand is treated as deterministic. However, even the best forecast tends to be inaccurate in actual practice. To account for forecast errors, some inventory models treat demand as probabilistic, but the parameters of the probabilistic distribution are usually assumed to be known. Current research shows little progress in isolating parameter estimation errors, or identifying non-parametric distribution patterns for describing demand patterns (Schwarz, 1981).

CHAPTER III

CONCEPTUAL MODEL

This chapter describes a conceptual model for a production-distribution channel system for the distribution of consumer goods. The conceptual model relates the numerous entities, activities, and factors, that interact dynamically in shaping the inventory management problems addressed in this research study. A clear statement of such system characteristics is important since the strength and weakness of various inventory replenishment methods depend, to some extent, upon the type of network in which they are being used (Doolan and Myers 1983).

The conceptual model also serves as a quick reference for comparing and contrasting the current research with earlier researches. Figure 1 shows the proposed model. The remainder of the chapter explains the conceptual model.

The conceptual model is a simple multi-echelon arborescent structure that captures the production function, the distribution function, product and information flows, and customer demands. Decision elements for both production and inventory management are included in the model.

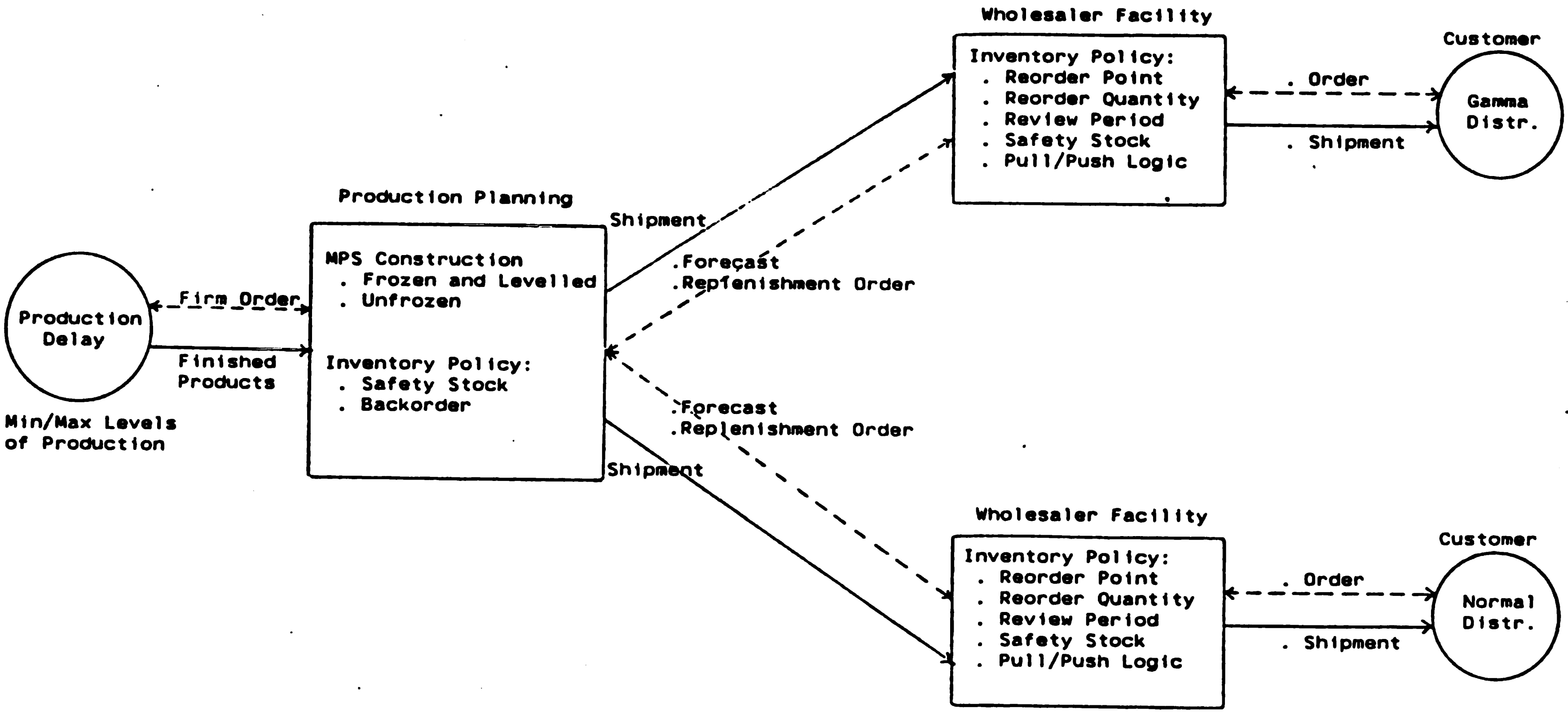


FIGURE 1. A CONCEPTUAL MODEL

The simplicity of the conceptual model is desirable, since models intend to organize and simplify reality. A two-echelon arborescent structure is the simplest structure for representing a single manufacturing facility supplying inventories to two wholesaler facilities. A recent survey study (Lambert, 1978) reported such a channel structure, from the manufacturer level to the wholesaler level, for 10 channels among 18 distribution channels for consumer goods being surveyed.

The conceptual model assumes independent ownership of the manufacturing facility and wholesaler facilities, thus each facility would operate under independent policy and inventory stocks. The wholesaler facilities obtain inventory supply only from the manufacturing facility, which in turn ensures inventory availability through planned production.

For consumer goods distribution systems, it is common to define separate stock keeping units for items with different options, color and packaging sizes. This study considers a family of products that shares similar physical and functional characteristics, and all have similar cost factors.

Customer demands appear on a daily basis at the wholesaler facilities. Two demand patterns are introduced to enrich the model representation. One of the wholesaler facility encounters demand pattern with gamma distribution, and demand for the second wholesaler facility is normally distributed. Gamma distribution is a common demand pattern at wholesaler level, while normal demand pattern is introduced for its theoretical significance (Buffa and Miller, 1979). Both demand patterns have known mean, variance, and seasonal factors. Aggregated demand forecasts from both wholesaler facilities become forecast inputs for production planning at the production facility. Figure 2 illustrates the process of aggregating demand forecast, followed by the deaggregation of demand forecast for production planning. Unfilled customer demands due to inventory shortage trigger backorders, which are satisfied through expedited shipments rather than from the regular replenishment shipment.

The conceptual model permits comparison of a Pull System and a Push System, when applied to manage inventory replenishment for the wholesaler facilities. Since inventory review frequency significantly affects performance of inventory policies, it is controlled in the conceptual model by adopting periodic review for both the Pull and the Push Systems. Inventory replenishment lead time, which accounts for order communication, order processing, and shipment time, is represented by a Gamma distribution with known parameters (Burgin, 1975).

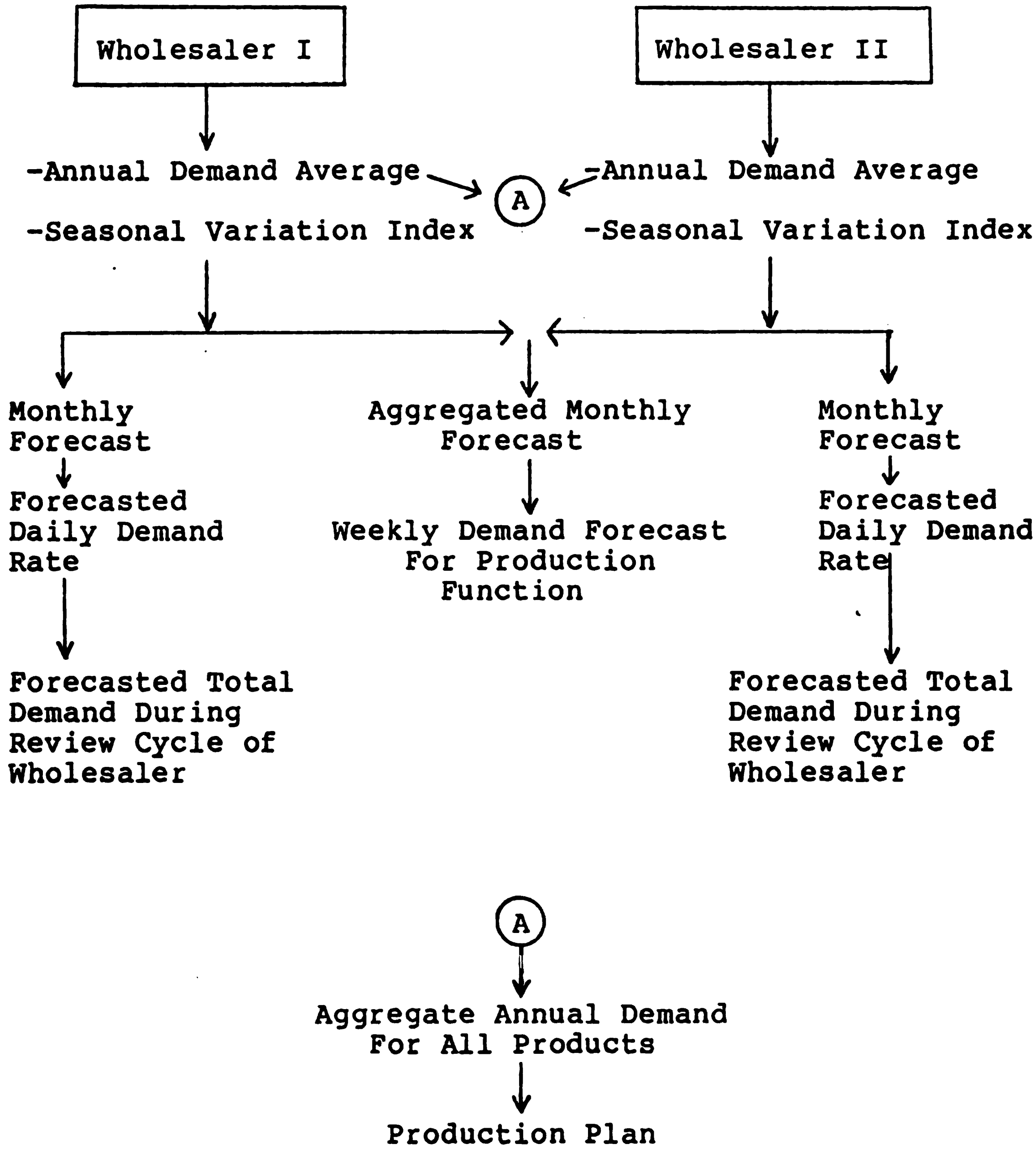
When inventory stockout occurs at the manufacturing facility, unfilled orders are backordered until inventory is available from production process. Inventory production is initiated by production order released through the planning of master producton schedule (Martin,1983), which is constrainted by a maximum and a minimum daily production level, and must sum up through time to match a predetermined annualized production plan.

Since the model considers inventory problems during a time horizon of 6 to 24 months, the usual time horizon for production plan (Tersine, 1984), both the production plan and capacity plan are fixed. During this time period, tactical readjustment of resources may be desirable, but no major shift in average demand level or adjustment of production capacity would occur.

The master production schedule either maintains the same production level from period to period or allows variable production quantities in different periods. A variable master production schedule adjusts production levels in response to both changes in demand level and backorders. Released orders pass through a multi-stage production process, with finished goods coming through the production line after a total lead time described by Erlang distribution (Manetsch 1977).

Figure 3, summarizing the production activities and information flows, includes explicit representations of production plan, capacity plan, forecast information, master production schedule, job orders, job queues, and a continuous production process. Figure 4 illustrates the

Forecast



Daily Total Demand Forecast:
(Aggregated Annual Demand Forecast / 260)

Month:	J	F	M	A	M	J	J	A	S	O	N	D
No. of 5 days week:	5	4	4	5	4	4	5	4	4	5	4	4

Figure 2: Structure of Demand Forecast

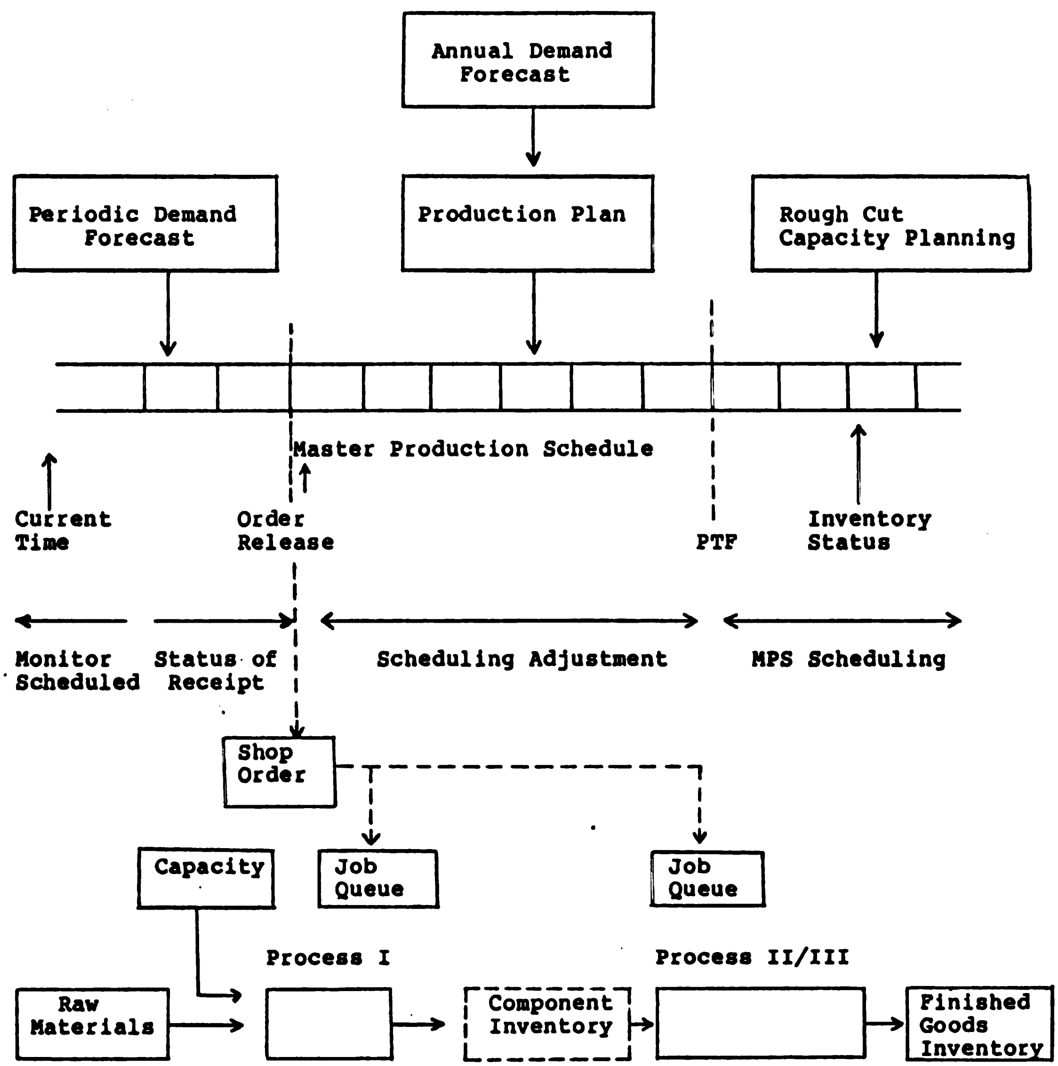


Figure 3: Production Activities and Information Flow

Production Process/Specification of Product Family

Purchased components: B, C, E, F, G, H, I, J, K, L

Manufactured components: A, D

Process I: both A and D

Process II: item I and III

Process III: item II and IV

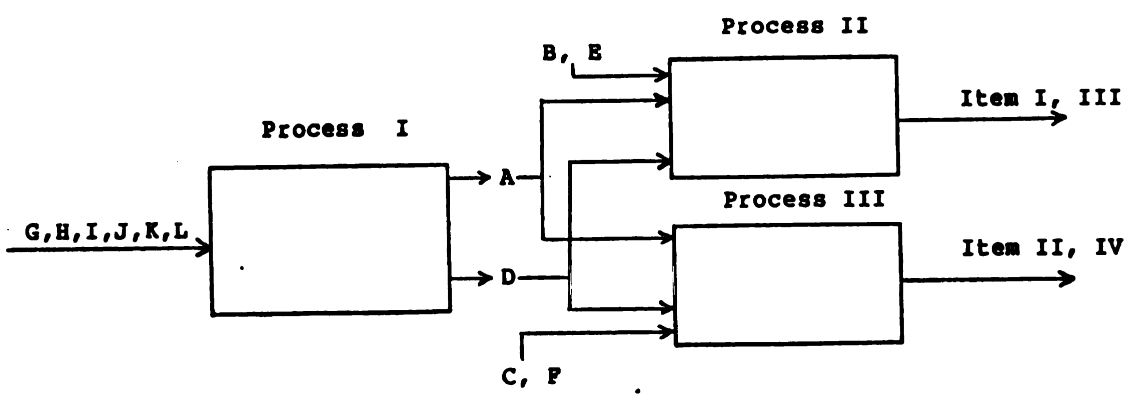


Figure 4: Production Process

dependent relationship among products through the sharing of components and production processes.

Each fabrication process is a multi-stage continuous process, and orders released into the process become indistinguishable. Figure 5 reveals the mathematical representations of the fabrication process. For the purpose of simplifying the model, only the input to the component production process (process I) is capacitated.

Because of the high cost of production capacity adjustment, real life production systems often handle seasonalized demand through anticipation inventory stock to minimize fluctuation in capacity levels. The conceptual model considers seasonal demands so that one can study the interaction of inventory policies across functional boundaries, under the influence of capacity constraints, especially during periods with accumulation of anticipation stocks, and periods with production capacities below demand levels.

With the emerging concept of just-in-time, many business firms place inventory savings as a top priority, as seen in manufacturers like Ford and General Motors who maintain less inventory in their just-in-time production plants. Ford reports inventory reduction through smaller lot size, faster and more reliable transportation, and elimination of safety stock (Feldman, 1984). The lower inventory level implies less protection from cycle stock against uncertainties - both in replenishement lead time and demand level. A tightly coupled production-distribution environment, as characterized by just-in-time systems, is considered in the conceptual model, for investigation of impact of such production environment on performance of lower echelon channel members.

Lastly, the model captures the principle of safety stock policy because of the controversy concerning the desirability of safety stock, as well as the positioning of safety stock in a channel of distribution.

Distributed Delay (A Flow Process)

Definition: VIN: Daily Work Load Input

R(k): Output from First Stage

R(k-1): Output from second stage

R(1): Daily Output From Production Process

Where VIN is capacitated with a maximum capacity.

R(1) = R(1) + [R(2) - R(1)] * DT/DEL

R(2) = R(2) + [R(3) - R(2)] * DT/DEL

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R(k) = R(k) + (VIN - R(k) * DT/DEL

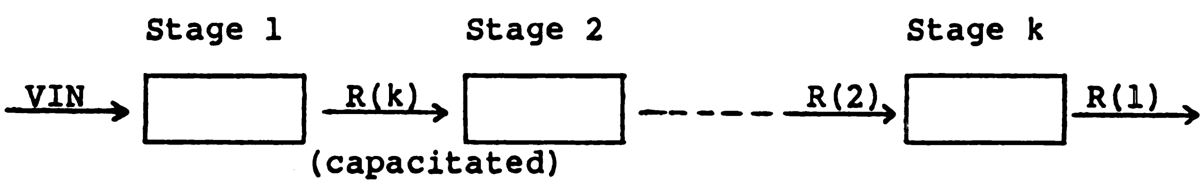


Figure 5: Distribution Delay Function
(Representation of Production Flow)

CHAPTER IV

RESEARCH METHODOLOGY

4.0 CHAPTER CONTENTS

This chapter documents the development of a simulation model that embraces the system characteristics presented in the conceptual model, and explains procedures for experimentation and data analysis.

The chapter, orgainized into seven sections, begins with the discussion of the overall design and characteristics of the simulation model. Section two explains the simulated inventory policies and manufacturing policies, and the associated design considerations. The next two sections present parameter estimation and model validation for the enriched simulation model, followed by sections on experimental design and hypotheses. Finally, a section on data analysis completes the chapter.

4.1 SIMULATION MODEL

Dynamic simulation was employed to study the interaction of inventory policies at the production-distribution functional interface. Simulation allows a very rich representation of the environment. This study incorporated manufacturing policies, distribution inventory replenishment approaches, stochastic demand patterns, stochastic lead time, and simultaneous measurement of inventory levels and quantity fill rate, into a simulation model. The exploratory nature of this study makes simulation especially suitable as an evaluative and comparative tool.

The design or selection of a simulator is very important for a simulation study. Elaborate efforts and much time will be required for designing a simulation model. The availability of well designed models relieves some of the burdens of model construction.

This section focuses on the selection criteria and enrichment of an existing distribution inventory simulation model. A simulation model suitable for the current research should:

1. be theoretically sound, and flexible enough to allow inclusion of elements of interest;
2. provide a dynamic environment for simulation;
3. allow representation of both the Pull and Push inventory replenishment approaches;

4. show a representation of the manufacturing environment, or a clear linkage to it;

5. allow probabilistic demand and lead time components, and a choice of forecasting techniques;

6. permit simultaneous measurement of inventory level and service level, and have a flexible report generator; and

7. be proven for application to distribution problems, and be readily accessible.

The Simulated Product Sales Forecasting (SPSF) package, developed at Michigan State University, served as the simulation vehicle. The SPSF model has the following characteristics:

1. The design of the model, initiated in 1970, has been validated through numerous applications. SPSF adopts a modular design, allowing flexible selection of system network and activities.

2. SPSF is a dynamic simulator.

3. The basic design of SPSF supports both the Pull and Push replenishment approaches.

4. The model includes a production module. Clear linkage between production and distribution activities allows flexible representation of the production activities.

5. The forecast module allows selection of forecasting techniques, and permits random generation of demand and lead time.

6. The model has been designed to trace basic operating activites, thus permitting the collection of information in addition to cost measurements.

7. The model has been used in several major research efforts, and is readily available at Michigan State University.

In order to include manufacturing policy decisions in the current research study, some model enrichment to the SPSF would be desirable. In brief the major modifications include:

1. the representation of the specific inventory policies chosen for comparison in this study. The inventory policies will be discussed in a later section;

2. the enrichment of the production environment so that it represents the two master scheduling strategies. The detailed procedures will be discussed in a later section. In addition, a multiple product, multi-stage production process is implemented; and

3. the alteration of the report generator to reduce the size of the report, and to include the appropriate activity data, as well as adding an interactive simulation mode.

For a description of the enriched simulation model, see Appendix A.

4.2 INVENTORY AND MANUFACTURING POLICIES

4.2.1 Inventory Policies

The selection of inventory policies to represent Pull and Push Systems is complicated by the fact that inventory policies under the two approaches often follow similar inventory management actions. On the other hand, inventory policies adopting the same replenishment approach do not always follow similar management actions. Besides, there are hybrid "Pull-Push" inventory models.

For example, I-T-E recently converted from a centralized (Push) inventory deployment concept to a decentralized one (Pull). Although their regional distribution centers replenished inventory by reorder points, I-T-E also emphasized in their newly adopted inventory control strategy, communication, as well as centrally established product stocking strategies and decision rules (Schneider, 1983). This section would clarify the confusion by first examining the various inventory decision factors, parameters, and the Pull or Push characteristics of inventory policies. Presentation of the specific inventory policies being investigated will follow.

First of all, factors which are common to all inventory policies include safety stock, demand patterns, forecast quality and inventory review period.

Safety stock decision, relevant whenever elements of uncertainty cannot be ignored, is basically a function of the lead time demand and its variability, and therefore can be determined independent of inventory policies. In this study, safety stock levels were selected independent of inventory policy. The criteria of selection will be discussed in a later section.

Demand patterns shape effectiveness of inventory policies. The fundamental differences between many inventory models lie in the assumption concerning the demand pattern. For example, economic order quantity

(EOQ) models assume constant demand pattern, while other probabilistic inventory models may assume a normally distributed demand pattern, and yet others like material requirement planning models assume variable, but deterministic demand levels at different time periods. This study subjected all inventory policies pairs to identical demand patterns, in an effort to control influence of demand patterns on inventory performance.

Since management usually makes inventory decisions in anticipation of future demand, quality of demand forecast is very important for inventory management. However, different inventory models have different assumptions concerning quality of forecast information quality. For example, EOQ models assume availability of aggregated demand forecast, while MRP model assumes availability of demand forecast at the weekly level. In order to remove the effect of information quality, the research design provided equal accessibility of forecast information to all inventory systems investigated.

Lastly, inventory review frequency has a strong influence on performance of inventory policies (Gross and Soriano, 1969). Trade-offs between system responsiveness, and economies of scale, determine the desirable review period. A continuous review inventory system tends to respond to demand changes, but sacrifices the potential cost savings with periodic review through economy of scale. This research adopted a one week review period, as often adopted in practice, for all inventory policies being studied.

Some policy elements are characteristics of either the Pull or the Push Systems. The economic order quantity and a reorder point are often associated with Pull System. With seasonalized demand forecast, these parameter values can be dynmically updated (Tatevasion, 1981), as is the case for this study. The Push System employs dynamic demand forecast to compute periodic replenishment quantity, but without the use of reorder point. The two inventory management systems also differ in the handling of replenishment orders by the manufacturing facility. Under the Pull System, random arrival of independent replenishment orders, issued by wholesaler facilities, are usually filled in the order of arrival. Inventory shortages at the central facility often lead to uneven distribution of inventory among wholesaler facilities. Central control of replenishment process in the Push system facilitates, when needed, allocation of limited inventories.

In order to focus on attributes that distinguish the Pull System from the Push System, the research design adopted similar values for parameters and factors that are associated with both systems - namely, safety stock levels, demand patterns, demand forecast, and inventory review period. The implication being that the

Pull, and the Push inventory policies being compared in this study, shared many common characteristics.

The Pull System adopted a Min/Max inventory decision rule. The minimum level, the reorder point, is computed as the expected demand during average replenishment lead time and review period, plus an amount of safety stock assigned by the experimenter. The maximum level has been set equal to one week of inventory supply above the reorder point, ensuring a minimum order quantity of one week supply of inventory. Both the reorder point and the maximum inventory level were adjusted according to the seasonal index. During the weekly inventory review, an inventory position below the reorder point would trigger a replenishment order. A later section of this report will elaborate on the relationship between the replenishment quantity and cost implications.

The Push System reviewed and replenished inventory weekly. The weekly replenishment quantity provided sufficient inventory coverage for projected demand during the next period, based on dynamic demand forecast. Safety stock inventory was determined independently. When there was insufficient inventory at the manufacturing site to satisfy all order requests, relative net requirements determined the quantity of inventory to be allocated to each wholesaler facility.

The inventory stocks of the manufacturing facility was continuously replenished by daily outputs from the production process. Replenishment orders from lower echelon facilities were filled from on-hand inventory. Inventory stockouts at the manufacturing level were handled through backordering of unfilled quantities, with immediate dispatch of currently available inventory. Backordered quantities would be shipped when the entire backorders could be filled.

4.2.2 Manufacturing Policies

This study considered a production environment with two alternative manufacturing policies, which represent two major strategies for planning the master production schedule (MPS) (Vollmann, William and Whybark, 1984).

The production environment consisted of a multi-stage production process, with production capacity shared by several products, all have similar characteristics, cost structures, and similar production processing. Such production environment is representative of a product line with an assortment of colors, packagings, and accessory features. The production facility has been restricted to fixed capacity levels within the time horizon specified in this study. The production activity levels were constrainted by a maximum capacity, and a minimum level which ensured adequate utilization of the capacity.

The master production schedule (MPS) maintained weekly buckets for planned orders, which coordinate the production activities. Sufficient time buckets were included to cover the total production and procurement lead time, with four additional monthly buckets. Weekly revision of the MPS allowed adjustment of production levels with respect to capacity and inventory availability.

The first manufacturing policy adopted a MPS with chase strategy, which emphasizes responsiveness of the production schedule to demand variations. The chase strategy allows the master production schedule to follow the marketplace, reacting to demand fluctuations. The schedule allows variable production levels, modifiable up to the point when production process must start in order to meet scheduled demands. In other words, the MPS is frozen for a period equivalent to the production lead time, i weeks. Beyond the i-th week time fence, any adjustment to the MPS is subjected to the maximum capacity availability, and minimum resource utilization constraints. This MPS strategy has been adopted by firms like Ethan Allen Furniture Company (Vollmann, William and Whybark, 1984).

The second manufacturing policy employed a levelled MPS strategy, which prescribes stable production levels to eleminate the instability and costs associated with workers hiring and firing in a variable production rates environment. In this approach, the MPS is frozen for a period of j weeks, a longer period than that adopted in the first policy. Moreover, all the time buckets must be levelled every month within the time frame of j weeks. A time fence is established, so that planned production level within the time fence cannot be altered, except in the presence of capacity-related problems. Adjustment to the MPS can be made beyond the j-th week time fence, but the adjustment must be evenly distributed among weeks within the same month, and is subjected to capacity constraints. This second policy, which has been observed in the production systems of Japanese automakers, tends to provide a more stable production environment. The advantage of levelled MPS is potential improvement in productivity (Hall, 1985).

The accumulation of backorders would trigger adjustment of the MPS beyond the i-th week time fence for the chase strategy, but MPS adjustment was pushed beyond the j-th week time fence for the levelled strategy. In both cases, adjustment of MPS could not alter the total production volume of the production plan.

A multi-stage distributed delay function captured the time lag between the release of production orders, and the output of the first unit; as well as the variable output rates in the batch processing production environment. At the beginning of each week, orders were released to job queues, awaiting production processing at daily rates regulated by capacity availability. Daily inventory outputs were immediately transfered to the finished goods inventory stocks.

Detail description of the production activities will be discussed in the following sections.

4.3 EXPERIMENTAL FACTORS AND PARAMETERS

This section presents and justifies factor representations and parameter values for the simulation model. Factors and parameters that remained unchanged throughout the study included product structure, demand patterns, replenishment lead time pattern, production plan, capacity plan, master production scheduling rules, lot sizing rules, priority rules, production backlog policy, and specifications for the production process. Each of these are addressed in this section. The section continues to discuss the selection of performance measures, and factor levels for experimental factors, and ends with a summary of the model factors and parameter values.

4.3.1 Product Structure and Demand Patterns

The conceptual model relates to the inventory management problem of a product line with four items, all sharing common components and production facilities. Figure 6 presents the bill of material for the product

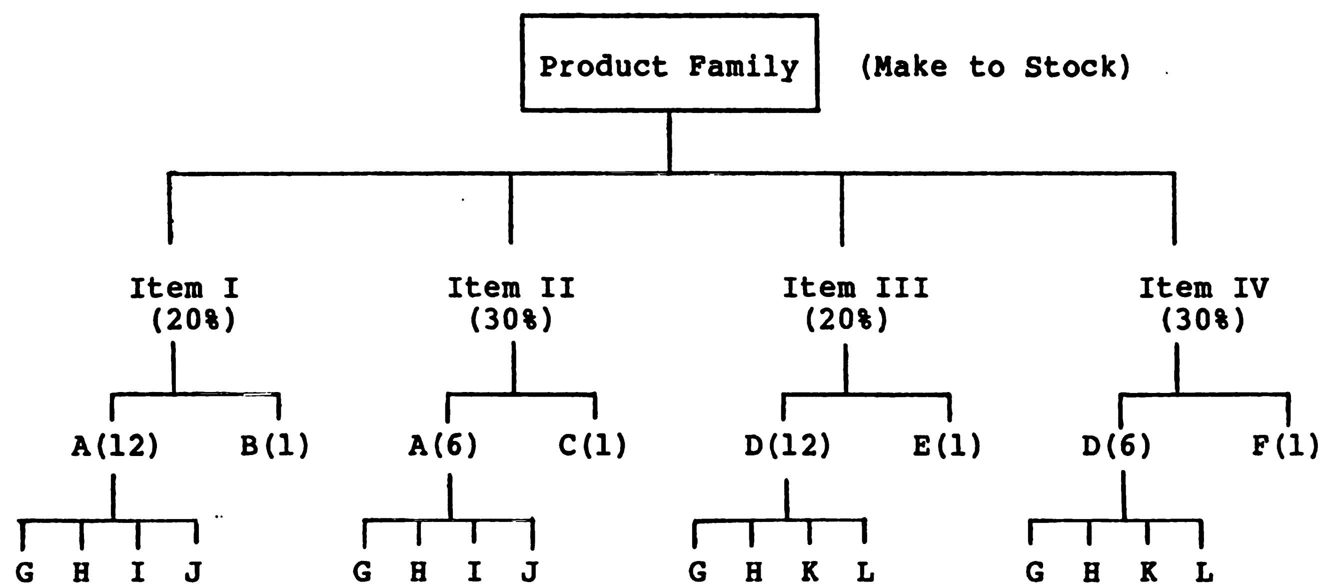


Figure 6: Product Structure of Product Family Selected in This Study

family, which shows a relative demand of 20% in two of the items, and 30% for the other two. Of the three production processes, the two components, A and D, share a common fabrication process. End items I and III compete for a second production process, while items II and IV vie for a third production process.

This hypothetical product structure provides a good representation for packaged consumer goods product structure.

The average daily demand of the product family at each wholesaler facility has been chosen to be an even 1000 units. Demand for each item was computed according to the relative demand ratio presented in Figure 6. Gamma and normal distributed demand patterns were assigned to each of the two wholesaler facility as indicated in the conceptual model. Seasonal factors on demand assumed values between .76 and 1.24, closely assemble those of the unrefillable beverage industry and some home appliances (Jones and Riley, 1984). In addition, occurrence of random fluctuation in demand levels was represented through coefficients of variation, for which values reported in the literature range from .11 (Krajewski *et al*. 1981; Farrell, 1985), to as high as 1.1 (Sanford and Farrell, 1982). Recently, a report appearing in the *Traffic Management* magazine (Farrel, 1985) estimated the distribution forecast error at between 10% to 50%. Thus this study adopted coefficients of variation at .11 and postponed until the section on model validation.

4.3.2 Replenishment Quantity and Cost Implications

A major consideration in the research design was to remove, as much as possible, parametric differences in inventory management actions between the Pull System and the Push System. Since review cycle significantly affects inventory policy performance, adopting a weekly inventory review cycle for all inventory policies would minimize advantageous performance of any inventory policy due to shorter review cycle. With the weekly review period, the order quantity is more reasonably set at approximately a week's supply, instead of following strictly the cost optimizing economic order quantity. This procedure removes the effect of order size difference on the average inventory level under various inventory policies.

Another group of parametric differences are the cost factors. Many inventory models, including the EOQ model, assumes known inventory order cost and holding cost. Recently, frequent changes to the inventory holding cost followed fluctuation in interest rates and inflation. On the other hand, setup cost (or order cost) is no longer immutable, especially when it becomes the target of vigorous cost reduction under recently emerging management concepts such as just-in-time production

(Jackson,1981). This calls into question the wisdom of management solutions derived from static cost values.

An alternative approach is to express cost factors as a cost ratio (R). For example, the economic order quantity formula can be expressed as,

$$Q = [\,2DR\,]^{.5}$$

where Q is the economic order quantity
D is the average annual demand
R is the ratio of order cost (Co) over annual unit holding cost (Ch)

Expressing the cost ratio in terms of the other factors yields:

$$R = Q^2/2D$$

For weekly inventory review, and an order quantity of approximately one week of inventory supply, assuming the order quantity is in the neighborhood of the economic order quantity, the results from this study apply toward a broad range of items having the implicit cost ratio, R. For instance, with the order quantity equivalent to 5 days of inventory supply, then

$$Q = 5D/260 = 5d \qquad \text{where } d = D/260$$

and $$R = 25d^2/520d = .048d$$

Given d=200, then R=9.165 and represents many possible pairs of cost factors, (Co,Ch). To name a few, (80,8.32), (50,5.2) . . .etc.

4.3.3 Order Processing and Replenishment Lead Time

The timing and quantity of inventory replenishment for the wholesaler facilities have been discussed under the inventory policy section. Lead time for replenishment is addressed here.

Replenishment lead time encompasses delays in order communication, order processing, and order shipment. Among the three delays, order communication is the least significant delay, especially with availability of sophicated electronic communication systems. It is also the most controllable. This study assumed the order communication delay to be negligible.

Order processing includes order entry, and order picking. For many firms, order entry is directly linked to the order communication system, and accounts for very little delay. However, delay in order picking depends on inventory availability. The conceptual model handles inventory stockouts by immediate shipment of partially filled orders, while backordering unfilled portions of orders backordered. Therefore, order picking delay is assumed to be insignificant when inventory is immediately available. Additional delays for backorders would occur when inventory stockouts occur.

Lastly, order shipment time is perhaps the longest, and least certain delay. Under deregulation and the recent movements in just-in-time procurement, some carriers reported improvements in delivery dependability (Beilock and Freeman, 1986). However, many shippers still encounter uncertain order shipment time.

Based on reported values in literature (Krajewski et al. 1983; Lalonde and Zinszer 1978; Lambert 1980), this study adopted a gamma distribution for representing the lead time, with an average lead time of 4 days, and coefficients of variation of .14 and .5 respectively. Backorder shipments had the same lead time distribution.

4.3.4 Production and Capacity Plans

Annual production targets for the various facilities have been estimated from average daily demand forecasts, assuming 5 work days per week, and 52 weeks per year. Figure 7 shows the procedure for estimating the production targets. The production plan in Figure 8 considers seasonal variations while attempting to maintain stable production levels from period to period. According to expected demand level, the plan fully satisfies annual expected demand for items II and IV, while allowing an ending inventory of 1000 units for each of item I and item III.

A capacity plan that supports the production plan is also included in Figure 8. Although firms usually adjust capacity over the long run to accommodate market changes, Annual Demand per Wholesaler (5 days week, 52 week year)

	Annual	
Item I (200 daily)	52,000	units
Item II (300 daily)	78,000	units
Item III (200 daily)	52,000	units
Item IV (300 daily)	78,000	units
Total	260,000	units

Annual Demand for production function (2 wholesalers)

Wholesaler I	260,000	
Wholesaler II	260,000	
	520,000	units/annual
or,	2,000	units/day

Figure 7: Estimated Demands

Daily Capacity	Min. level	Ave. Util.	Max. Level
Process I	14.4K	16.8K	20.0K
Process II	.6K	.8K	1.0K
Process III	1.0K	1.2K	1.5K

Planned Weekly Capacity and production plan for various months

Production Volume/week	J	F	M	A	M	J	J	A	S	O	N	D
Item I	2000	1700	1700	1700	2000	2000	2000	2300	2300	2300	2000	2000
Item II	3000	2500	2500	2500	3000	3000	3000	3500	3500	3500	3000	3000
Item III	2000	1700	1700	1700	2000	2000	2000	2300	2300	2300	2000	2000
Item IV	3000	2500	2500	2500	3000	3000	3000	3500	3500	3500	3000	3000

Planned Capacity Requirement (thousands/week)
(Planned Capacity Available) (thousands/week)

	J	F	M	A	M	J	J	A	S	O	N	D
Process I	84	70.8	70.8	70.8	84	84	84	97.2	97.2	97.2	84	84
	(84	72.0	72.0	72.0	84	84	84	100	100	100	84	84)
Process II	4	3.4	3.4	3.4	4	4	4	4.6	4.6	4.6	4	4
	(4	3.5	3.5	3.5	4	4	4	5	5	5	4	4)
Process III	6	5	5	5	6	6	6	7.0	7.0	7.0	6	6
	(6	5	5	5	6	6	6	7.5	7.5	7.5	6	6)

Figure 8: Production and Capacity Plans

capacity changes will not likely occur in the short run. Therefore both the production plan and the capacity plan were kept unaltered during the relatively short time horizon in this study. For this reason the planned capacity levels have been selected to cover maximum production needs, with slight variation resulting from idle capacity.

A recent research indicated that 12% idle capacity is representative in U.S. production environments. In some cases, up to 15.6% capacity slack has been observed (Krajewski et al., 1983). This implies that approximately 18.5% increase above the normal production level is possible. On the other hand, in order to retain the workforce and justify the investment on equipments and facilities, manufacturers desire the maintenance of a minimum level of production activities. The extant literature reveals little on the minimum production level, perhaps due to the ease of contracting production activities. Jackson recently reported a tolerable level of 10-20% change in production level (Jackson, 1983).

In this study, the capacity was set at 100,000 units/week for process I to support the peak level production needs. In accordance with literature citations, the peak capacity level is approximately 19% above the normal capacity level of 84,000 units/week, while the minimum capacity level of 72,000 units/week is about 15% below normal level. Capacities for Process II and Process II have been determined with similar criteria. The normal capacity levels of all Processes have been computed to support average demand levels.

4.3.5 Master Production Scheduling

The master production schedule translates the production plan into weekly production requirements. Dynamic changes in forecast information and backorders are the major factors for periodic adjustments to the master production schedule. While one might examine numerous master scheduling rules, this research considered only two. Figures 9a, 9b, and 9c present a summary of the two MPS approaches.

In order to compare the relative effectiveness of the two MPS approaches, one must control the MPS structure, and parameter values for both approaches. A survey questionaire was sent to 40 executives of firms involved in physical distribution activities. Based on the survey responses (Appendix B) and values quoted in literature (Krajewski et al., 1983), this study adopted a 7 month planning horizon, with 13 to 18 variable length weekly buckets, and 4 monthly buckets. Information explicitly used in master production scheduling include periodic demand forecasts, scheduled receipts quantities, adjusted production schedule, and inventory levels.

SEQUENCE OF ACTIVITIES IN MPS (CHASE AND LEVELLED)

Beginning of week

↓

Roll in Master Schedule

↓

Adjust length of weekly horizon

↓

Measure Forecast Error

↓

Estimate Current Period Available Capacity

↓

LOOP until period before order release

Compute Cumulative forecast (SF) (PLTFST)

Compute Cumulative Scheduled Receipt (SSR) (MPS)

Compute Projected inventory position
(POH(I) = OH + SSR(I) - BOQ - SF(I))

END LOOP

↓

Advance to Order Release period

↓

Select Chase or Levelled MPS Rule

Figure 9a: Master Production Scheduling

CHASE MPS

```
LOOP for each product

  Compute POH(I) = POH(I-1) - Period demand forecast F(I)

  Compute priority = POH/weekly forecast

  Record priority of product

END LOOP
↓
LOOP (in order of product priority)
        stop when capacity is fully assign, exit Master
        scheduling.

   IF    POH(I) < Safety Stock
   THEN  , Release the larger of a minimum lot size or
           POH adjusted to multiple of physical lot size.
         , Release order
         , Reserve capacity, flag capacity shortage,
         , Record difference between released order
           and planned order levels
  END IF
ENDLOOP
↓
IF  unassigned capacity available
  LOOP  until capacity fully assigned, or end of order.
        Start with product with highest priority.
        Estimate level of production required to achieve
        inventory target.
        PR = (SS + Production Target Deviation) - POH
        If PR > 0, add PR to released order.
         . round order to multiple of physical lot size
         . adjust order size difference record
         . adjust capacity requirement until fully assigned
  ENDLOOP
↓
IF minimum capacity utilization level of process I not
   acheived, then add unit physical lot to products in
   order of priority,
↓
IF weekly horizon is 13, break monthly forecast evenly
   into weekly forecast.
↓
SET weekly planned order level according to production
    target for the new month.
```

Figure 9b: Chase MPS procedures

LEVELLED MPS

```
LOOP for each product

   Compute POH(I)=POH(I -1) + Planned Order PO(I) - F(I)

   Compute and record priority= POH/weekly forecast

ENDLOOP (product)
|
v
IF capacity available

   Release planned order in order of increasing priority
   value
|
v
RECORD
       Production Adjustment=Released Order - PO(I)
|
v
IF weekly horizon is 13, roll in monthly bucket

  Compute,

  Projected requirement = Monthly Production Target
   for month              + Backorders
                          - Production Adjustment
ENDIF
```

Figure 9c: Levelled MPS procedures

This study assumed the cumulative demand forecast and the production plan to remain valid over the planning horizon. However, actual demand levels may deviate from the periodic forecast levels. In order to measure the validity of the cumulative forecast, cumulative demand levels were compared with the cumulative forecast levels to yield the cumulative forecast errors. This was operationalized in the master schedulings by comparing the forecast of each period with actual order received.

Quantity of scheduled receipts is another important source of information for production scheduling. When periodic arrival of finished products from the production process deviates from the scheduled quantity, the MPS must be able to detect the discrepency. In order to trace the arrival of finished goods, the cumulative anticipated scheduled receipts levels were compared with actual scheduled receipts. The adjusted schedule receipts for any period i can be expressed as:

$$SRi = SRi + SOD$$

$$SOD = SSR - SAR$$

where

SRi	is planned scheduled receipts for period i
SOD	is shipment overdue
SSR	is the cumulative scheduled receipts
SAR	is the cumulative actual receipts

For both MPS approaches, adjustments to released production orders were disallowed. The "Chase MPS" allowed adjustment of order during order release period, while the "Levelled MPS" allowed adjustment only in the monthly buckets. Whenever the number of active weekly buckets fell below 13, the MPS divided the most recent monthly bucket into levelled weekly buckets. Figure 2 in Chapter Three listed the number of weekly bucket for individual calendar months.

During order release time at the beginning of each week, the "Levelled MPS" releases the planned production levels, but the "Chase MPS" would calculate and release a net requirement for the period based on cumulative demand forecasts up to the period, cumulative scheduled receipts, and on-hand inventory levels. Capacity limitations require the establishment of a priority rule, which has been defined as projected days of inventory supply (projected on-hand inventory divided by weekly demand). The highest priority for capacity assignment was given to the item having the least days of inventory supply. Hence, planned production quantities were released as shop orders in order of decreasing priority, up to the weekly capacity limits.

Released shop orders were held in job queues, awaiting the cumulation of sufficient quantities to be released as job batches. Each job batch represented an economical quantity derived through cost trade-offs between production set up cost, inventory carrying cost, and physical lot size. For this study, the MPS must release orders in multiple of 100 units.

Lastly, the two MPS approaches differed in the backorder handling procedure. The "Chase MPS" schedules additional production activities for backorder at current order releasing period. However, for a "Levelled MPS", adjustment of production schedule to accommodate backorder is allowed only at the monthly buckets. Figures 10, and Figure 11 highlight the shop orders flow and the scheduling activities.

4.3.6 Multistage Production Process

The multi-stage production process consists of three distinct processes. Process I is dedicated for fabrication of two components , A and D. Process II or process III is used for completing the production of the four items. In a 1983 study of a large group of production facilities, a mean production routing of 4 stages and a mean production time of 3 weeks (15 days) have been reported (Krajewski et.al. 1983).

Process I in this study represented 3 production stages with a total lead time of 12 days, and each of process II and process III represented a single production stage with mean processing time of 3 days. A lot size requirement of 1000 units per job batch was imposed on process I. Batch size of 100 units applied to process II and III. Figure 12 summarizes the job queueing activities.

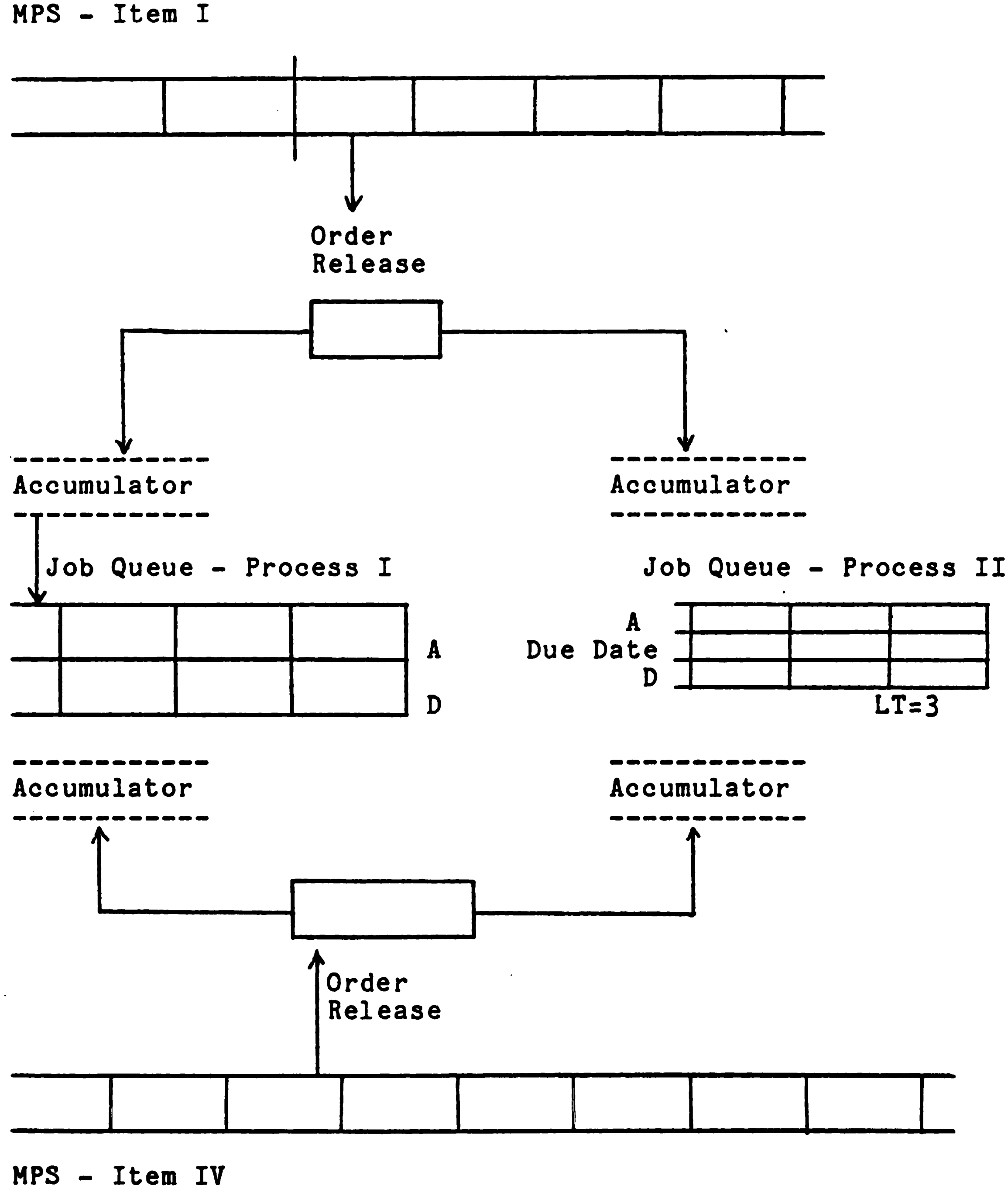


Figure 10: Shop Order Flow

SCHEDULING PLANNED ORDERS

Chase MPS:

Planned Requirement for month i	=	Production Target for month i

Levelled MPS:

Planned Requirement for month i	=	Production Target for month
	+	Backorders
	-	Production Adjustment

where,

Production Target	is a function of forecast and capacity availability.
Backorders	are unfilled customer orders due to inventory shortage
Production Adjustment	is cummulative order release difference from targeted level in all previous period.

Rules are:

1. Addition of backorder to production schedule is subjected to slack capacity availability.
2. Production adjustment is equivalent to cumulative unreleased order quantity not been adjusted.
3. Maximum adjustment for any month must be less that capacity surplus, which is the difference between available capacity, and the minimum capacity ultilization level.
4. The MPS schedule should sum up equal to production plan continuously over extended planning horizon.
5. For both frozen and unfrozen MPS schedule, weekly requirement is obtained by equally dividing the monthly requirement into weeks.

RESCHEDULING RULES (unreleased orders only)

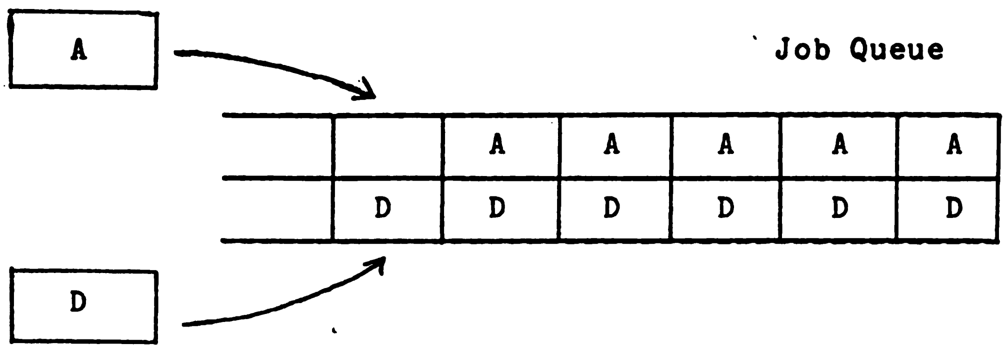
Chase MPS	: rescheduling is subjected only to capacity availability
Levelled MPS:	no rescheduling allowed within PTF, except deletion of planned order, when capacity shortage occur.

Figure 11. MPS scheduling rules

PROCESS I

Work is loaded in batches of 1000 units of A or D component. Work is done on first in first out basis. Incomplete batch wait in job queue until a full batch is accumulated.

The Job queue release up to 20000 units (20 batches) daily into the shop floor for Process I.



(Each time order is received, A and D accumulator will send single batch to Job Queue in alternative order until all complete batches are sent to Job Queue.)

Process II/III

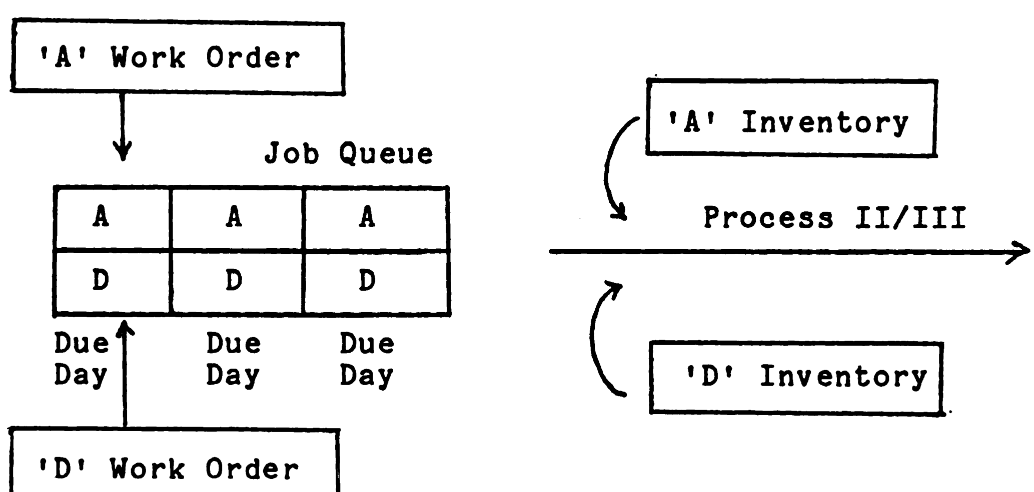


Figure 12: Job Queue - Process I,II/III

4.3.7 Experimental Factors

This study investigated four factors that are often addressed independently in previous researches. Three of the factors - inventory approaches, manufacturing policies, and uncertainty levels, have been discussed earlier. Safety stock location will be discussed next.

For given level of uncertainty and desired service performance, one can determine the level of safety stock with statistical approach. That level is commonly stated either as a fixed quantity or in terms of days of inventory supplies. The approach of time supplies of inventory has been selected for the study both because of its simplicity and because it is independent of the actual demand level.

However, the statistical approach is for single facility, but there are three facilities in the conceptual model. If one could assume perfect replenishment coordination between the production facility and the wholesaler facilities, then safety stock is required only at the wholesaler facilities to protect against demand and lead time uncertainties. For each wholesaler facility in the conceptual model, if demand and lead time are independent and normally distributed, the theoretical safety stock level can be computed through the formula:

$$SS = (k * SDc)/D$$

where, SS is the safety stock level in time supplies
k is the safety factor
SDc is the joint standard deviation of demand over lead time (L), plus review period (R)
D is the average daily demand

The joint standard deviation SDc can be computed as:

$$(SDc)^2 = (R+L)*(SDd)^2 + D^2*(SDrl)^2$$

where, SDd is the standard deviation of daily demand
SDrl is the standard deviation of leadtime and review period

Given that R and L are independent, and assuming a constant review period, the standard deviation for lead time plus review period can be simplified as:

$$(SDrl)^2 = (SDr^2 + SDt^2)$$

$$= SDt^2$$

where, SDr is the standard deviation of review period
SDt is the standard deviation of lead time

Also, for given coefficients of variation of lead time (CVt), and demand (CVd), the standard deviations of demand and lead time can be expressed in terms of the average value,

$$SDd = CVd * D$$

$$SDt = CVt * L$$

Therefore, the formula for the joint standard deviation can be simplified as,

$$(SDc)^2 = D^2 * ((R+L)*CVd^2 + CVt^2*L^2)$$

Thus, the safety stock level can be expressed as a function of the safety factor, k, mean lead time, L, review period, R, and the coefficients of variation:

$$SS = k * [(R+L)*CVd^2 + CVt^2*L^2]^{.5}$$

See Table 2 for the theoretical values for safety stock at various levels of lead time and demand uncertainties.

In order to find the desirable safety stock level for the entire distribution system, safety stock level for each of the two wholesale facilities can be determined by the statistical approach. For service level targeted at between .85 to .92 fill rate, the computed values for each facility are approximately .5 day time supply for low uncertainty environment, and 2.0 days time supply for high uncertainty environment with .5 coefficient of variation.

Since the computed safety stock levels protect against both demand and lead time uncertainties, there is no further need for safety stock at the higher echelon production faciltiy, except for protection against production uncertainties. However, the proper approach to resolve production uncertainties is through better

Table 2: Theoretical Safety Stock Levels (days of supply)
(Review period, R=5 days;Leadtime, L=4 days)

Coefficients of Variation: Demand	Coefficients of Variation: Leadtime	.85	.90	.95	.99
	Desired Quantity Fill Rates	.85	.90	.95	.99
	K Factors	1.04	1.28	1.64	2.33
.11	.14	.68	.83	1.07	1.51
.50	.14	1.66	2.05	2.63	3.73
.11	.50	2.11	2.59	3.32	4.72
.50	.50	2.60	3.20	4.10	5.83

planning and more vigorous maintenance program, rather than safety stock. Therefore it is not necessary to consider additional safety stock, and the system safety stock level can be set equal to the total sum of the safety stocks at the two wholesaler facilities.

Two other problems require further considerations. Initially, all system safety stocks were positioned at the wholesaler facilities. However, the research design also considered positioning safety stock at the manufacturing facility. Using the law of large number, the same amount of safety stock should provide at least equal level of protection when positioned at the higher echelon manufacturing facility instead of the wholesaler facilities. Although many real life inventory systems position some safety stock at both echlelon levels, the postioning of entire safety stock at either echelon level allows strong representation of just-in-time inventory management philosophy. It is expected that the lean safety stock level would intensify interaction between cycle stocks and safety stock strategies.

Lastly, the computed safety stock level was not exact because one demand pattern, and the replenishment lead time experienced gamma distribution. Furthermore, interaction of cycle stock with safety stock, as well as interaction of inventory across echelon levels would have unpredictable effects on service performance. Since this study has been designed to investigate such interactive effects, the exact safety stock level, and the ability to predict the corresponding service performance, were of secondary interest.

4.3.8 Summary of Factors and Parameter Values

Major assumptions and parameter values adopted for this simulation study, including all those discussed in previous sections, are summarized in Figure 13, Figure 14 and Table 3. Additional information on the simulation model and initial parameter values are included in Appendix C.

Table 3. Summary of Factors and Parameter Values

FACTORS/PARAMETERS	**VALUES**
Production Facility	
Production Process	3 processes, 4 stages
Total Production Delays	15 days
Production Capacity	
Process I	Average 84,000 units/week Minimum 72,000 units/week Maximum 100,000 units/week
Process II	Average 4,000 units/week Maximum 5,000 units/week
Process III	Average 6,000 units/week Maximum 8,000 units/week
Master Production Schedule	
Planning Horizon	8 months, 13 - 18 weekly buckets, 4 monthly buckets
Scheduling Options	2
Product Family	2 families, 4 end items
Inventory Safety Stock	0,.5,and 2.0 days supplies
Wholesaler Facility I	
Demand	Distribution Pattern: Gamma Average Daily Demand: Item 1 : 200 units Item 2 : 300 units Item 3 : 200 units Item 4 : 300 units Coeff. of Variation .11 & .5
Inventory Policies	2 (Pull/Push)
Safety Stock	0,.5,and 2.0 days supplies
Replenishment Lead Time	Distribution Pattern: Gamma Average Lead Time: 4 days Coeff. of Variation .14 & .5
Wholesaler Facility II	
Demand	Distribution Pattern: Normal Average Daily Demand: Item 1 : 200 units Item 2 : 300 units Item 3 : 200 units Item 4 : 300 units Coeff. of Variation .11 & .5
Inventory Policies	2 (Pull/Push)
Safety Stock	0,.5,and 2.0 days supplies
Replenishment Lead Time	Distribution Pattern: Gamma Average Lead Time: 4 days Coeff. of Variation .14 & .5

Assumptions on Production Planning and Master Scheduling

I. Production Planning
- A Planning horizon of two year is adopted.
- Total Annual Demand Forecast is available, with seasonal variations and random fluctuation, demand pattern repeating for two years
- A seasonally adjusted production plan, and associated planned available capacity and utilization guidelines are established.
- There will be no revision of the production plan.
- There will be no revision of demand forecast.
- Statements are given, concerning:
  - initial inventory level
  - final inventory level at year end
  - safety stock level
  - monthly achievement of production target
- Production lead time: 3 weeks
- Lot size:
  - Process I: 1,000 units of component
  - Process II: 100 units of end item
  - Process III: 100 units of end item

II Master Scheduling
- MPS planning horizon - variable, 8 months horizon
  - up to 18 weeks weekly horizon
  - 4 months monthly horizon
- Firmed order period: 13-18 weeks variable weekly horizon
- Planning time fence: end of firmed order period
- Split monthly forecast into weekly forecast when weekly horizon is reduced to 13.
  Splitting rules:
  For Frozen MPS :even splitting of monthly forecast to all weeks,
  & For unfrozen MPS :subject to minimum production level.
- Priority rules for scheduling:
  Planning : use priority rule
  P=(POH - Target INV)/weekly forecast
  Rescheduling: use priority rule
  P=(POH)/weekly forecast
  (smallest P receives highest priority)
  (POH represents projected onhand inventory level)
- Lot size rule:
  physical lot size: increment of 100 units.

Figure 13: Quick Reference to Basic Assumptions

ESTIMATION OF CAPACITY AVAILABILITY

Available Capacity = Planned Available Capacity
- Maximum amount of jobs exceeding allocated capacity of any process

PRIORITY OF ORDER RELEASE AMONG PRODUCTS

A priority status is computed through

P= (Projected Inventory Position/ current period forecast) *(class weight of product)
The smallest P value has the highest priority.

RELEASED ORDER

. A work order for all released orders will be sent to each of the work station involved.
. Together with each weekly release, a weekly capacity assignment will be allocated to each work station.
. So each work station would have
  - a job queue (batches or partial batches of job)
  - a capacity pool (dated capacity)

JOB QUEUE AND PROCESSING TIME

Work order for each work station is placed into a Job queue with infinite capacity, work orders are grouped and released as job batches. Incompleted batch will not be processed until future arrival of work orders to complete a batch.

The priority rule for job queue is first in first out, and alternating between all products requiring service of the work station.

Process I is a continuous flow process with lead time of 12 work days over three production stages.

Process II and III are single stage process with processing time of 3 days.

Figure 14: Basic attributes of production process

4.4 MODEL VALIDATION

4.4.1 Validation Procedure

The validity of the simulation model plays a vital role in establishing the credibility of a simulation experiment. A valid model is not proven to be valid under all sets of conditions. Instead, a degree of confidence is established for the model for the application it is developed for (Sargent,1979). Sargent (1979) and Shannon (1982) point out three important questions:

1. Does the simulation model behave as a model builder believes?
2. Does the simulation model adequately represent the system for the objectives it was developed? and
3. Does the simulation model user have confidence in the model's results?

Various techniques and approaches can be used to answer these questions, but there are currently no known procedures for validating a simulation model. Some of the techniques that are commonly accepted are Verification, Internal Validity, Face Validity, Traces, Parameter Validity, Historical Methods, Multi-stage Validation, Sensitivity Analysis, Models comparision, Historical Data Validation, Predictive Validation, Event Validity, Hypothesis Validity and Submodel Testing.

However, since the proposed simulation model does not replicate the operation of an actual system, validation using historical data is not possible. In order to reduce the cost of validation, validity of submodels that have previously been validated are accepted whenever possible. Procedure for validation is as follows:

1. Verification: review the computer model carefully to show that the conceptual model has been truly represented in the simulation model.

2. Internal Validity and Model Comparisons: using the initial runs, the amount of stochastic variability in the model are observed and corrected when necessary. Simulation model behaviors are compared with theoretical values.

3. Face Validity: the logic of the basic SPSF model has previously been validated. In this application, the correctness of the production environments and inventory policies require further validation. Face validity of these model structures are obtained through literature review and the expert judgment of the dissertation committee.

4. Hypothesis Validity: each submodel is individually verified and tested. Behaviors of submodels are carefully monitored, and compared with the behavior of hypothesized systems. For submodels that are adopted, evidence of model validity are sought. Examples are the demand generator, and lead time generator, and backorder queue. Time phase relationship of major variables are examined to ensure consistency with anticipated model behavior.

5. Variable-Parameter Validity: the selected values for variables and parameters are compared with those of actual business systems.

6. Traces and Sensitivity Analysis: some initial runs are made to ensure model behaviors are within expected ranges. In particular, the sensitivity of the model to initial values and random number streams is tested. Tracing of entities is performed when abnormal model behaviors develop. The ranges of output variables are carefully monitored to ensure that expected information from all experimental runs will provide sufficient information for proper analysis.

This procedure can provide answers to questions one and two raised above. Question three can be answered through the appropriate choice of parameter values and model representations, which have been discussed in detail in previous sections. Documentation of the validation evidence follows.

4.4.2 Evidence of Model Validity

The simulation model adopted a modular design, which has the advantage of allowing individual testing of submodels. The simulation model consisted of 10 functional submodels in addition to numerous activity control submodels. Appendix A listed the functional submodels and their roles.

The logic flows and sequences of event occurence in submodels have been carefully monitored and have shown to follow the desirable activity sequences specified by the conceptual model. Furthermore, elaborate tracing of output variables, internal variables, and storage variables provided sufficient evidence that the conceptual model was adequately represented. Model verification was completed through careful documentation of the functions of submodels, interrelationships between submodels, and variable definitions. Appendix A outlined the activity flows of submodels.

Initial simulation runs generated outputs with reasonably low variance under different uncertainty environments. The ranges of output responses were slightly wider than theoretically predicted ranges, which was acceptable, because of the interaction of safety stock at multiple echelon levels (Cook, 1981). Detailed tracing of intermediate variables indicated that they were within reasonable ranges. The simulator were able to handle special conditions such as production backlog, and component shortage, even when it was subjected to uncertainty conditions beyond the ranges required for the current study. Diagnostic messages were implemented and tested for detecting situations when resource limitations of the simulator were being exceeded. Table 4 shows sample results from one stage of the internal validity test. The simulation outputs under the influence of difference random number streams indicated the simulation outputs were influenced but not greatly affected by random fluctuations. Similar internal validity test have been performed for all experimental conditions being considered in this study. However, other numerical

Table 4 Internal Validity Test Results

Replicate *	Average Inventory Level	Average Service Level
1	2469	.980
2	2439	.997
3	2482	.949
4	2465	.965
5	2446	.986

* replicates under five different random number streams

evidence of internal validity have been omitted from this report because of the large volume of data, but have been properly documented and filed for future reference.

The logic of the simulator was vigorously scrutinized through literature review, survey results, and has been reviewed by the dissertation committee. Since SPSF has been validated previously in numerous applications, the focus of validation was on the production modules. Several revisions of the simulator design have been conducted as a result of the face validity tests. Moreover, values of variables and storage arrays have been traced throughout simulation runs, allowing detailed examination of the performance characteristics of the simulator.

After face validation of the simulator, each submodel was subjected to more detailed testing. Behaviors of the submodels were compared with the hypothetical relationships being represented. Appendix D presents both graphical and statistical comparison of generated demand patterns with theoretical values. Furthermore, time series plots of several major variables are presented in Figure 15a and 15b.

Figure 15a presents time series of four variables for one of the products, under levelled MPS policy. The top series is the seasonalized weekly demand rate at a wholesaler facility. The second series is the weekly average inventory level at the wholesaler facility. The weekly production rate is shown in the third time series, and the last series is the weekly plant inventory level.

The horizon time axis of Figure 15a begins at the second half of the first simulated year, when the simulation model enters high demand season. The second time series shows a steady rise in wholesaler inventory along with increasing demand rate indicated by the first series. Since the simulation employs a fixed weekly replenishment cycle, the increasing inventory level is caused by the the higher levels of cycle stock required to meet increased demand levels.

At the same periods, the production rate can be observed to rise before rising demand levels, and it shifts back to normal at the peak of high demand season,

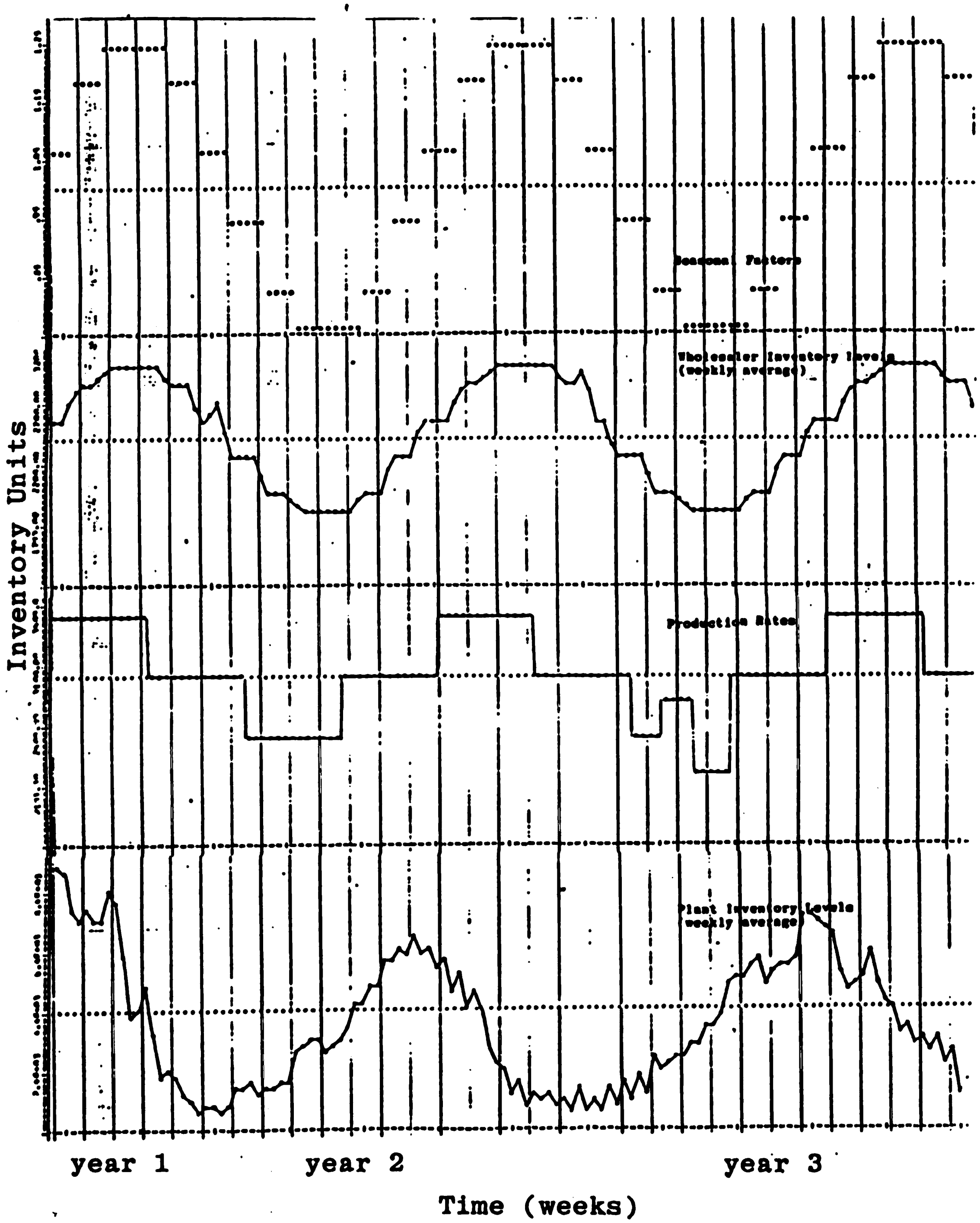


Figure 15a. Dynamic Relationships of Inventory Levels
(Levelled MPS)

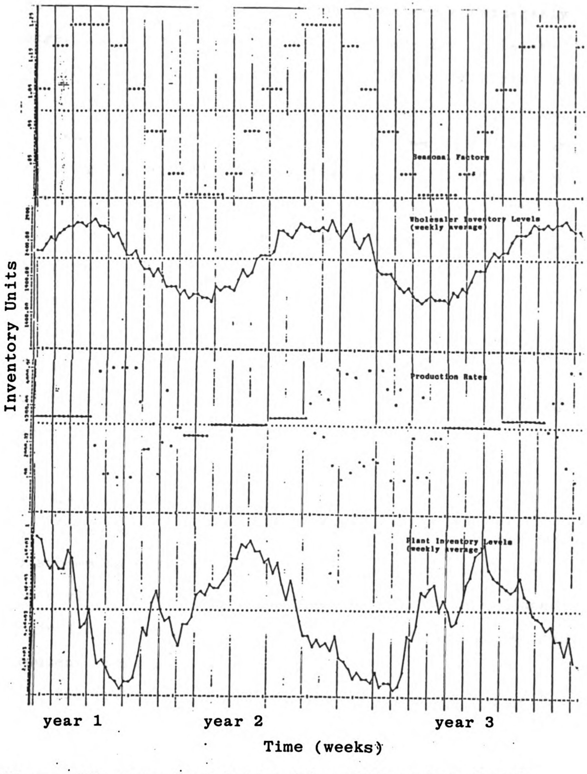


Figure 15b. Dynamic Relationships of Inventory Levels
(Chase MPS)

always leading the changes of demand levels. Moreover, the peak and trough of production rates are considerably longer that those of demand rates. There are at least two reasons for these relationships. First, for produce-to-stock items, increased level of production activities must start early enough to accommodate the lead time for producing and positioning the item before the arrival of high demand season, thus explaining the leading pattern changes of production rates. The reverse is true during the phase of declining rates, production rates return to normal at the point where sufficient inventory has been produced to meet the additional demand for the remainder of the high demand season. Unfortunately, these additional inventory, being in the distribution pipeline, cannot be clearly illustrated in Figure 15a.

The second reason for the time-phased relationship is capacity considerations. Since changing capacity is expensive, anticipation inventory stock is often employed to accommodate demands during peak demand seasons. Thus the early upward shifting of production rate is designed to produce anticipation stock, thus reducing the need for frequent changes in production level.

The irregular production rates toward the end of the second year are caused by tactical allocation of production capacity among different products. This is evidence for the dynamic interactions among multiple products, being modeled in this simulation study.

The time series on plant inventory levels requires close examination. The initial high inventory level is due mostly to initial inventory level adopted by the simulation study. Since the first simulated year is dominated by transient behaviors, we will begin examining the time series from the beginning of the second year.

The second year begins with below average demand level. However, operating the production facility at regular level leads to accumulation of plant inventory. The rate of inventory accumulation continues despite lower production rates during the low demand seasons. The inventory accumulation is anticipated in order to keep the work force, which generates a production rate above the demand rate during the low demand seasons. As soon as demand starts to rise from its lowest level, the production activities are returned to regular level, thus accounting for a steeper rise in plant inventory. When demand rises to above average level, shipping rate is faster than production rate, therefore plant inventory declines. As the demand rate increases, more inventory is positioned at the wholesaler facility than the plant, hence the continuous decline in plant inventory. Plant inventory remains at a lower level until demand returns to normal, and the lower demand season marks the beginning of another plant inventory cycle.

Sensitivity analysis was performed repeatedly throughout the simulation study, and due to the large number of variables employed in the simulation, only sensitivity of output variables to a selected group of parameters are listed in Appendix E. Unlisted parameters should not be interpreted as insignificant, or having no influence on response variables. Rather, their ommision is explained through the basic assumptions of the conceptual model.

Table 5 and Table 6 provide summaries of sources for selected parameter values. The selection criteria of these parameter values have been discussed in previous sections.

Table 5 Reference for Selected Parameters

Parameter	Value	Source
MPS types	Chase - Levelled	Vollmann,et.al. 1984
MPS Planning horizon	13 - 18 weeks	Survey, 1985; Krajewski,et.al,1983
Production lead time	3 weeks	Krajewski,et.al,1983
Production stage	4 stages	Krajewski,et.al,1983
Replenishment lead time	4 days	Krajewski,et.al,1983
Uncertainty levels	demand c.v.=.11 lead time c.v.=.14	Krajewski,et.al,1983
Safety stock levels	wholesaler: 0,.5,2.0 days of supply plant: 0,.5,2.0 days	Theoretical value (Tersine,1982) Hall,1983
Seasonal factors (monthly)	(.94 , .82, .76, .76, .82 , .94,1.06,1.18, 1.24,1.24,1.18,1.06)	Closs,et.al,1983; Beverage Industry, 1985
Review period	1 week	Design
Order quantity	appoximately 1 week supply	Design
Reorder point	seasonalized expected demand during lead time and review period, plus safety stock.	Theoretical value (Tersine,1982)
Demand pattern	Gamma,daily mean=200 Normal,daily mean=200	Design

Table 6 Selected Survey Summary from Industrial Survey

Parameter	Mean	Standard Error	Standard Deviation	Min Value	Max Value
MPS planning horizon (week)	54.829	5.1	77.1	1	999
Percentage(%) of MPS on schedule	82.4	1.1	16.1		
Production lead time - internal (w/o purchasing lead time)(week)	8.34	.713	11.11	1	999
Production lead time - include purchasing(week)	24.748	1.641	25.531	2	150
Production plan horizon (week)	50.00	4.164	54.448	4	523

(by Ronald Pannesi, unreported dissertation study, figures shown are average response of 245 U.S. firms representing a wide spectrum of industry)

Remark: Production planning horizon is trimodal at 12, 26, and 52 weeks respectively

4.5 EXPERIMENTAL DESIGN

The simulation experiment employed a factorial design, which provided an economical and structured approach for studying the proposed research problems. The experimental design and related design considerations are presented in this section.

The full factorial design consisted of 4 factors, each with two factor levels, yielding a total of 16 treatments (Table 7). The factors and selected factor levels are as follow:

Factors	Levels
1. Replenishment Approach	. Pull . Push
2. Manufacturing Policies	. Levelled MPS . Chase MPS
3. Uncertaintes Level	. High . Low
4. Safety Stock positioning	. Wholesaler facility . Production facility

Major characteristic difference between the Pull System and the Push System were captured as two factor levels of replenishment approach. Special precaution was taken to assign identical values to both approaches for common policy parameters such as order quantity, review period, and forecast quality.

Two manufacturing policies - the levelled and chase master scheduling strategies, were included as factor levels to study the effect of supply conditions. These have been discussed in detail in previous sections.

Table 7. Treatments in Experimental Design

CASE	A INVENTORY APPROACH	B MFG. POLICY	C UNCERTAINTY LEVEL	D SS POSITION
1	-	-	-	-
2	-	-	-	+
3	-	-	+	-
4	-	-	+	+
5	-	+	-	-
6	-	+	-	+
7	-	+	+	-
8	-	+	+	+
9	+	-	-	-
10	+	-	-	+
11	+	-	+	-
12	+	-	+	+
13	+	+	-	-
14	+	+	-	+
15	+	+	+	-
16	+	+	+	+

A. + represents PUSH inventory replenishment approach
- represents PULL inventory replenishment approach

B. + represents Levelled MPS
- represents Chase MPS

C. + represents leadtime c.v. = .5; demand c.v. = .5
- represents leadtime c.v. = .14; demand c.v. = .11

D. + represents safety stock position at plant
- represents safety stock position at wholesaler

Two uncertainty levels were included in the experimental design because both the Push System and just-in-time production are sensitive to information quality. Changes in uncertainty levels are not uncommon, due to competition, market changes, or changes in transportation service. One of the objectives of the experiment was to investigate the comparative performance of inventory systems under different environments of uncertainties.

Lastly, the two safety stock positioning strategies represented the practice of pushing all buffering stock toward lower echelon facilities (Sawchuk,1985), versus the concept of postponing safety stock at upper echelon facility (Jones and Riley, 1984). Criteria for selecting these factors have been presented in previous sections.

Coordinated through this experimental design, each experimental run consisted of a level of uncertianties for demand and lead time, a replenishment approach, a manufacturing production scheduling policy and allocation of safety stocks at one of the two possible echelon levels.

Rather than condensing simulated results into a single cost measure, two simultaneous measures of system performance for each experimental run were defined:

1. Average quantity fill rate at distribution facility
2. Average inventory position at distribution facility

Making two measurements of system behaviors enhances the chance of detecting impact of treatments and interactions on system perfomance. In addition, separate measurement of service performance and inventory performance allowed collection of empirical data through which the basic relationships between inventory policy, inventory investment, and service implication could be investigated independent of arbitrary cost parameters.

However, the need to use multivariate statistical techniques complicated data analysis. Issues related to data analysis would be discussed in a later section.

Since experimental outputs were average values, the next design consideration was to define a sample point (observation). Potential candidates were average values over weekly period, biweekly period, monthly period, quarterly, or semiannual period. Biweekly period, and monthly period were eliminated because of the weekly review cycle, and varying lengths of months. Each observation was defined as the six month average output responses over the high demand season, so that an entire season was being observed. Samples were collected during high demand seasons because problems of inventory shortage and service deterioation would be more prominent during such periods.

The next design question concerned the method of sample collection. The batch mean and the regeneration methods are inappropriate because of the two year horizon assumed in the conceptual model. Moreover, severe autocorrelation was expected for current simulation. Therefore, additional samples were collected through replicating the experiment with different random number streams.

To minimize the impact of transient behavior, a series of simulation runs were performed to test for steady state conditions under each treatment. Appendix F documents details on steady state analysis.

Since arrival of steady state conditions varied among the different treatments, but all indicated a stable pattern after two simulated years, the first two years of all runs were discarded as transient states, and data collection was started during the third year after resetting all statistics.

The full factorial design required 16 simulation runs per replication, with 780 simulated periods per run. The resulting computing resource requirement was sizable. This was an important factor in the sample size decision, to be discussed after the statements of hypotheses.

4.6 HYPOTHESES

For distribution system described by the conceptual model, with controlled values for inventory policy parameters such as review period, order size, information availability, and environmental uncertainties, the experiment was conducted for rejection of the following null hypotheses:

<u>Hypothesis I</u>:

Master production scheduling strategies do not significantly affect service and inventory performance at distribution facility.

<u>Hypothesis II</u>:

Push System and Pull System do not provide significantly different service and inventory performance at distribution facility under uncertain environments.

<u>Hypothesis III</u>:

There is insignificant interaction effect between safety stock positioning strategy and distribution inventory management approaches.

<u>Hypothesis IV</u>:

There is insignificant interaction effect between environmental uncertainty levels, and distribution inventory management approach.

The four hypotheses addressed the research questions raised in Chapter One. However, the experimental design providcd more information than those used in testing these hypotheses. Additional experimental observations will be presented in chapter 5.

4.7 DATA ANALYSIS

This research employed multivariate analysis of variance (MANOVA) for analysis of the two simultaneous output variables. For a full factorial experiment, MANOVA tests hypotheses that differences are zero for pairs of group means. There are several considerations in the application of MANOVA technique. First, assumptions of MANOVA must be satisfied. Moreover, additional analyses are often necessary to supplement and support the results of MANOVA when assumptions are violated. Lastly, sample size estimation is desirable to achieve the targeted confidence level at low experimental cost.

Application of MANOVA requires conformity to several basic assumptions. The first assumption concerns independence of error terms, which could be achieved through the collection of independent samples. The experimental design required independent replications in sample collection, thus satisfying this first assumption.

The next assumption requires homogeneity of variance, which could be tested by the univariate Cochran C test and the multivariate Box-M test. Since the basic experimental design introduces different levels of variance into different groups, it became necessary to transform data through a combination of the following techniques:

1. $INV^{*} = LOG_{10}(INV)$
2. $SVC^{*} = LOG_{10}(SVC)$
3. $SVC^{*} = SVC^{.5}$
4. $SVC^{*} = SVC^{2}$

where SVC^{*}, INV^{*} are the transformed variable, SVC and INV are the original response variable.

A typical inventory-service tradeoff curve shows an exponential increase in average inventory level as service level approaches 100 percent. Application of logarithm transformation coverts the non-linear relationship into a linear relation, with little change to the underlying relationship. On the other hand, squaring, or taking the square root of the service measure are transformations commonly recommended for equalizing variance (Neter and Wasserman, 1974).

Besides data transformation, covariate analyses could be considered for resolving the unequal variance problem. Details will be reported in Chapter 5.

Provided that the first two assumptions are satisfied, MANOVA is relatively robust to deviation from the normality assumption. The normality assumption were examined through normal probability plots of residuals. Details are postponed until Chapter 5.

MANOVA merely shows the existence of difference in group means, the exact difference and relative performance of various treatments could be ranked order by multiple comparison techniques. Two techniques - Tukey's method and Scheffe's method were employed. Tukey's method gives a very short interval, and is best for providing basic ranking of the treatment groups. On the other hand, Scheffe's method uses a stricter testing criterion and often results in a wider interval. Although Scheffe's method yields very conservative results, it has the advantage of making no assumption on the variance-covariance matirix. The multiple comparison tests are conservative in reporting group differences, but they serve to put a bound on experimental error.

Since difference level of variance have been introduced through the experimental design, the multiple comparison tests were repeated on two data subsets, which were divided according to the uncertainty level being introduced to the treatment groups. Removal of the uncertainty factor allows better separation of treatment groups under the combined infuence of the other three experimental factors.

The lack of conformity of data patterns to the MANOVA assumptions suggested that performing nonparametric analysis might be helpful. Since treatments were related through common random number streams, the Friedman test was employed by computing the test statistics:

$$T4 = \frac{12}{bkm^2 (mk + 1)} \sum_{j=1}^{k} [Rj - bm(mk+1)/2]^2$$

where b = 14 represents the number of replication

k = 16 represents the number of treatment groups

Rj is the sum of ranks of all replication for treatment group j

The null hypotheses that all treatments have identical effects would be rejected if T4 exceeded the .95 quantile of the chi-square distribution, with 15 degrees of freedom.

A multiple comparison test was also available if the Friedman test rejected the null hypotheses. Two treatment groups i, j would be considered different if the following inequality is satisfied.

$$|Ri - Rj| > t_{.95} \left\{ \frac{2kb(mk-1)\ VAR\ (Rj)}{(k - 1)(mbk - k - b + 1)} \left[1 - \frac{T4}{b(mk - 1)} \right] \right\}^{.5}$$

where Ri, Rj are sum of ranks for treatment i and j

$$VAR(Rj) = bm^2 (mk + 1)(k - 1) / 12$$

Lastly, a graphical presentation of experimental findings has been developed and presented in Chapter 5.

Neter and Wasserman (1974) suggested two approaches for estimating sample size requirements for factorial experiment. However, the power approach for planning sample size to control Type I and II errors is inapplicable because the total treatments of the current experiment exceeds tabulated values for an essential parameter. Hence sample size calculation was based on the estimation approach for controlling the widths of confidence intervals for multiple pairwise comparison in multiple comparison tests.

In order to calculate sample size, one must know the variance estimate, and the variance formula. From previous research experience, the estimated range of the service measurements fall between the range of .754 to 1.0 (Closs and Law, 1983). Therefore, an estimate standard deviation value, s , equals one-fourth of the observed range, or .0615.

There are several alternative formula for variance computation, depending on the assumptions. In the case when factors do not interact, or interact only in unimportant fashion (Neter and Wasserman, 1974), pairwise comparison variance for a 2x2x2x2 factorial experiment can be computed as,

Formula I: $$VAR = 2s^2/(2)(2)(2)n$$

where n equals to replications for each treatment.

When important interactions exist, the variance formula becomes,

Formula II: $$VAR = 2s^2 / n$$

A third alternative is to test the hypotheses of the existence of a given proportion of population, p. The variance in this case can be expressed as (Spurr and Bonini, 1973),

Formula III: $$VAR = [p(1 - p) / (n)]^{.5}$$

where n equals total sample size
p would equal 1/16 for the 2x2x2x2 factorial experiment

The variance estimates are then used to compute the half-width of confidence interval for Tukey multiple comparison test, T*SD, where SD is the standard deviation estimate, and,

$$T = q(.95 ; 2, (n-1)*2*2*2) / (2)^{.5}$$

Since the value of T is dependent on the sample size, the desirable sample size is determined by progressively increasing the value of n until a desirable confidence interval is obtained.

Following a conservative approach, the experimenter used the second formula in anticipation of important interaction effect, and a n value of 14 would provide a confidence interval half width of .08 for the service measurement. In another word, the experimenter was interested in detecting a one-tail difference of 8%

deviation of in-stock probability for pairs of treatment groups. The experimenter was willing to accept the interval width as a 95 percent family confidence interval because of the many contrasts being considered. Table 8 summarizes the computed half widths of confidence intervals under Tukey's Multiple Comparison technique. Therefore, a total of 224 samples were collected for the experiment.

Table 8: Sample Size Estimation

Tukey Multiple Comparison Test 95% Family Confidence Interval for Service Measurement:

Sample Size per Treatment (N)	Half Width of Confidence Interval Formula I	Formula II	Formula III
10	.030	.094	.066
12	.030	.086	.060
14	.028	.080	.056
16	.026	.075	.052

Tukey Multiple Comparison Test 95% Family Confidence Interval for Inventory Measurement:

Sample Size per Treatment (N)	Half Width of Confidence Interval Formula I	Formula II	Formula III
10	35.39	93.26	.0656
12	32.30	85.14	.0599
14	29.92	78.18	.0555
16	27.98	73.73	.0519

CHAPTER V

RESULTS AND ANALYSIS

5.0 INTRODUCTION

This chapter begins with the discussion on data transformations for conformity to MANOVA assumptions. Then hypothesis testings results from MANOVA are presented, followed by multiple comparison testing results. The chapter continues to present additional experimental observations not addressed through hypothesis testings. Presentations and discussions have been focused on results from the wholesaler facility experiencing gamma demand pattern, because there have been no major differences in performance between the two wholesaler facilities experiencing different demand patterns. Report on results from the second facility will be brief to avoid repetition. The chapter closes with a graphic presentation of research findings.

5.1 DATA TRANSFORMATION AND MANOVA ASSUMPTIONS

Two univariate tests - Cochran C and Bartlett-Box F, and the multivariate Box-M test were applied to the raw data for testing the homogeneity of variance assumption.

The raw data failed the test and were transformed using procedures outlined in Chapter 4. The most effective set of transformation procedures were by squaring the service responses while simultaneously taking logarithm of the inventory measurements. In addition, variables such as average plant inventory levels and backorder quantities have been introduced as covariates, hoping to equalize the variance, but failed to contribute any significant improvement. Thus all subsequent analyses would be using the transformed variables (INV, SVC) computed from the raw data by the relations:

$$INV = LOG10(INV_{old})$$

$$SVC = SVC_{old}^{2}$$

Results for the homogeneity of variance test on the transformed data could be found in Table 9. The disturbing fact was that both Bartlett-Box F and Box-M tests rejected the null hypothesis of homogeneity of variance at $p<.001$. However, knowing the robustness of MANOVA for data sets with equal sample size, and that evidence for homogeneity of variance was supported by the Cochran C test at $p>.01$, the suitability of the transformed data was accepted.

Table 9: Homogeneity of Variance Test Results

```
UNIVARIATE HOMOGENEITY OF VARIANCE TESTS
------------------------------------------------------------

VARIABLE .. INV

 COCHRANS C(13,16)            .14737, P = .074 (APPROX.)%
 BARTLETT-BOX F(15,22904) = 6.73529, P = .000           !

VARIABLE .. SVC

 COCHRANS C(13,16) =          .16119, P =  .026 (APPROX.)
 BARTLETT-BOX F(15,22904) = 7.26023, P =  .000

MULTIVARIATE TEST FOR HOMOGENEITY OF DISPERSION MATRICES
------------------------------------------------------------

BOXS M =                  263.99966
F WITH (45,65056) DF =      5.51631, P =    0 (APPROX.)*
------------------------------------------------------------

     % Crochan critical value (.05) = .1634
     ! F critical (15,22904)  = 1.66
     * F critical (45,465056) = 1.56
```

The normality assumption was slightly violated as indicated in Figure 16 and Figure 17. The skewness of the distribution partially explained the outcome of the highly sensitive Box-M tests. Since MANOVA would be robust to slight departure from normality when all treatment groups have equal sample size (Tabachnick and Fidell, 1983), the decision was to proceed with MANOVA for significance testing.

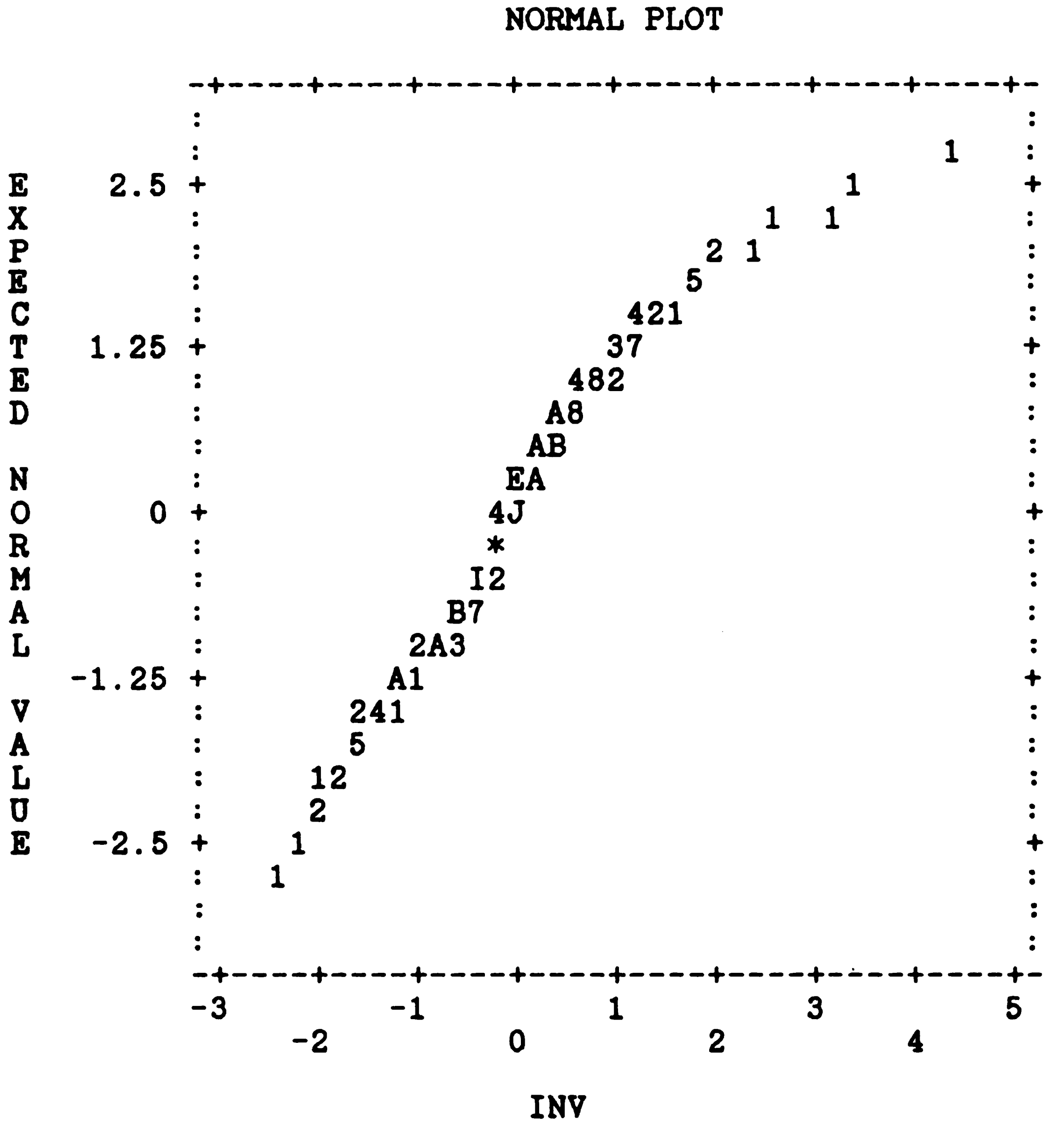


Figure 16: Normal Probability Plot of INV vs. Residuals

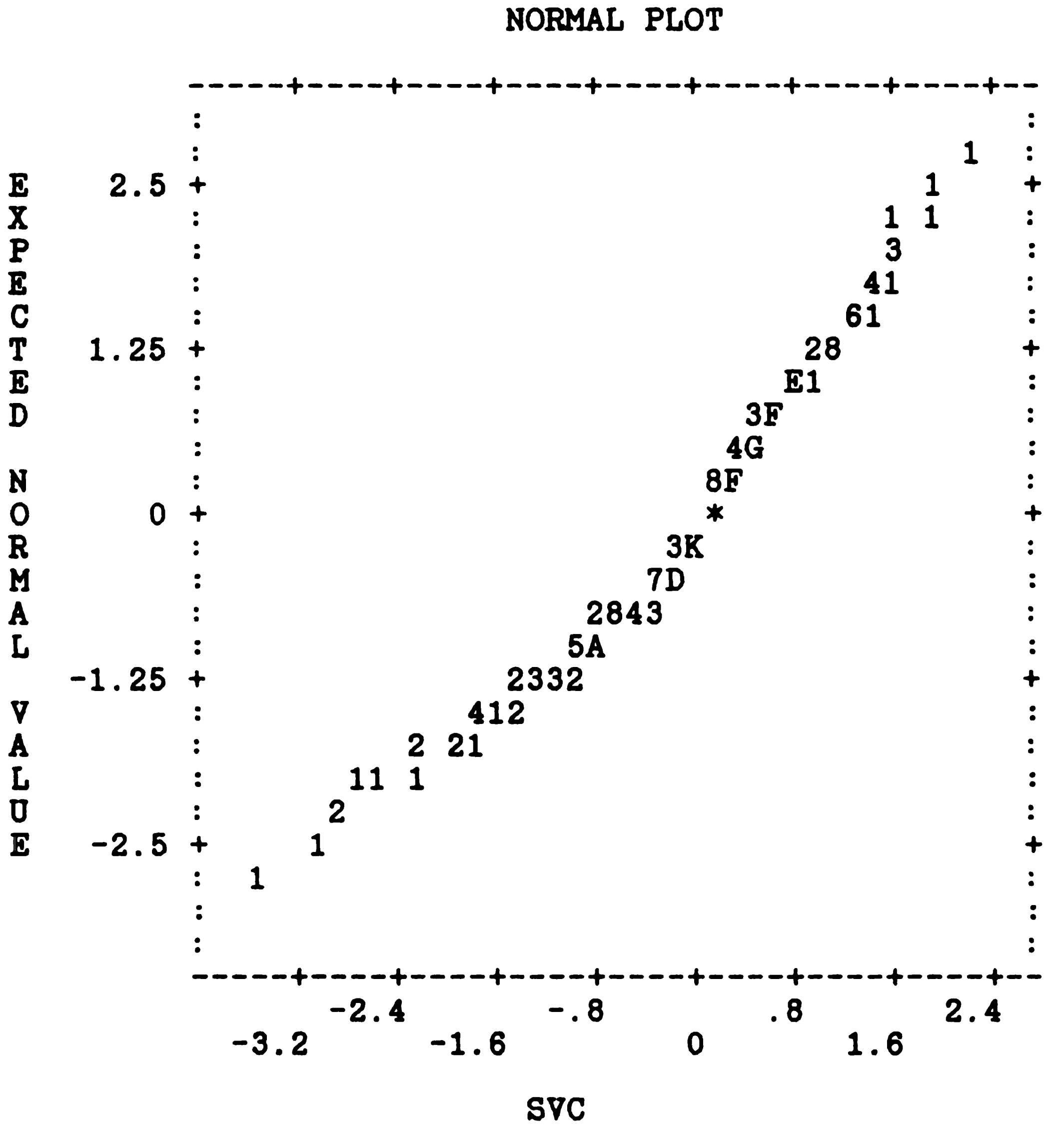


Figure 17: Normal Probability Plot of SVC vs. Residuals

5.2 HYPOTHESIS TESTING

A four-way multivariate analysis of variance was performed on two transformed dependent variables: average inventory level at distribution facility (INV), and average quantity fill rate at distribution facility (SVC). There were two factor levels for each of four independent variables. Data were collected from 14 replications of 16 treatments.

SPSSx MANOVA was used for the analysis. MANOVA performed multivariate tests of significance using four testing criteria - Pillais's Trace, Hotelling's Trace, Wilk's Lambda and Roy's Largest Root criterion. Table 10 reports testing results according to the Pillai's testing criterion, which is considered the most robust to departure from MANOVA assumptions (Norusis, 1985). For effects having significant multivariate testing results, the univariate F statistics helps to determine the relative contribution of variables to the overall performance difference. Table 10 also reports on the univariate significance testing results.

The presence of significant interactions among the effects A, C, and D suggested that testing results on these main effects should be interpreted with caution. Detail discussion on hypotheses testing would be presented along with the restatement of the hypotheses.

Table 10: Summary of Significance Test Results

EFFECT NAME	Multivarite F	Univariate F INV	SVC
Main Effects:			
A	4270.03 *	5901.41 *	13.46 *
B	13.24 *	16.88 *	24.45 *
C	976.23 *	1508.74 *	33.61 *
D	680.59 *	876.57 *	.14
Two-Way Interactions:			
A BY B	.97	.70	1.96
A BY C	1.68	2.54	2.81
A BY D	10.52 *	12.26 *	.11
B BY C	.70	.84	1.31
B BY D	.04	.07	.03
C BY D	638.69 *	770.35 *	3.46
Three-Way Interactions:			
A BY B BY C	.41	.67	.66
A BY B BY D	.55	.49	1.09
A BY C BY D	13.51 *	18.87 *	.80
B BY C BY D	.05	.10	.08
Four-Way Interactions:			
A BY B BY C BY D	.34	.46	.60

A : Inventory Replenishment Approach
B : Master Scheduling Strategy
C : Uncertainty Level
D : Safety Stock Positioning Strategy
(* significance at $p < .001$)

Note: same effects are significant at $p < .001$ for wholesaler facility experiencing normal demand pattern.

Hypothesis I:

Master production scheduling strategies do not significantly affect service and inventory performance at distribution facility.

Testing of this hypothesis was conducted through the significance test on main effect B. Table 11 shows all multivariate testing statistics rejected the null hypothesis at .001 significance level. Univariate F-test indicated that both service and inventory performance measures were significantly affected by master scheduling strategy at $p < .001$.

Hypothesis II:

Push System and Pull System do not provide significantly different service and inventory performance at distribution facility under uncertain environments.

Significance test on main effect A indicated that the null hypothesis was rejected by all multivariate testing statistics at .001 level (Table 12). Univariate F-test indicated that distribution inventory approaches significantly affected both service and inventory measurements at the $p < .001$. Although there was strong evidence for rejecting the hypothesis, the presence of significant interactions cautioned against making any simple statement concerning the relative effectiveness of the Push System and the Pull System. Further examination of the relative performance of the two systems is postponed until the next two sections.

Table 11: MANOVA - Testing Results of Hypothesis I

EFFECT .. B (MASTER SCHEDULING STRATEGY)

MULTIVARIATE TESTS OF SIGNIFICANCE (S=1, M=0, N=102 1/2)

TEST NAME	VALUE	APPROX.F	HYPOTH.DF	ERROR DF	P VALUE
PILLAIS	.11341	13.2392	2.00	207.00	.000
HOTELLINGS	.12791	13.2392	2.00	207.00	.000
WILKS	.88659	13.2392	2.00	207.00	.000

UNIVARIATE F-TESTS WITH (1,208) D. F.

VAR.	HYPOTH. SS.	ERROR SS.	HYPO.TH MS	ERROR MS	F	P-VALUE
INV	.00230	.02840	.00230	.00014	16.88	0
SVC	.40556	3.45043	.40556	.01659	24.45	0

Table 12: MANOVA - Testing Results of Hypothesis II

EFFECT .. A (REPLENISHMENT APPROACH)

MULTIVARIATE TESTS OF SIGNIFICANCE (S=1, M=0, N=102 1/2)

TEST NAME	VALUE	APPROX.F	HYPOTH.DF	ERROR DF	P VALUE*
PILLAIS	.97633	4270.029	2.00	207.00	0
HOTELLINGS	41.25632	4270.029	2.00	207.00	0
WILKS	.02367	4270.029	2.00	207.00	0

UNIVARIATE F-TESTS WITH (1,208) D. F.

VAR.	HYPOTH. SS.	ERROR SS.	HYPOTH MS.	ERROR MS.	F	P-VALUE*
INV	.80588	.02840	.80588	.00014	5901.41	0
SVC	.22336	3.45043	.22336	.01659	13.46	.000

*Critical values(.05): F(2,207) = 3.04; F(1,208) = 3.89
*Critical values(.01): F(2,207) = 4.71; F(1,208) = 6.76

Hypothesis III:

> There is insignificant interaction effect between safety stock positioning strategy and distribution inventory management approaches.

The third hypothesis was tested through the two-way interaction effect "A BY D", which was significant at the .001 level according to all multivariate statistics (Table 13). Univariate F-test indicated that the two-way interaction effect "A BY D" was significant only for inventory measurement, but not for service performance. A pooled within-group correlation of -.591 between the two dependent variables implied that, despite the conclusion of the univariate F-test, any effect that affects the INV measure should also affect the SVC measure.

Hypothesis IV:

> There is insignificant interaction effect between environmental uncertainty levels, and distribution inventory management approach.

The significance testing result on effect "A BY C" failed to provide sufficient evidence to reject hypothesis IV at .05 level. Table 14 summarized the test results.

The significance of the main effects C (uncertainty) and D (safety stock position) were of no surprise. Although significance of the three-way interaction effect

Table 13: MANOVA - Testing Results of Hypothesis III

EFFECT .. A (replenishment approach) BY D (safety stock strategy)

MULTIVARIATE TESTS OF SIGNIFICANCE (S=1, M=0, N=102 1/2)

TEST NAME	VALUE	APPROX.F	HYPOTH.DF	ERROR DF	P VALUE*
PILLAIS	.09228	10.52163	2.00	207.00	.000
HOTELLINGS	.10166	10.52163	2.00	207.00	.000
WILKS	.90772	10.52163	2.00	207.00	.000

UNIVARIATE F-TESTS WITH (1,208) D. F.

VAR.	HYPOTH. SS.	ERROR SS.	HYPOTH MS.	ERROR MS.	F	P-VALUE*
INV	.00167	.02840	.00167	.00014	12.26	.001
SVC	.00184	3.45043	.00184	.01659	.11	.739

Table 14: MANOVA - Testing Results of Hypothesis IV

EFFECT .. A (replenishment approach) BY C (uncertainty level)

MULTIVARIATE TESTS OF SIGNIFICANCE (S=1, M=0, N=102 1/2)

TEST NAME	VALUE	APPROX.F	HYPOTH.DF	ERROR DF	P VALUE*
PILLAIS	.01595	1.67735	2.00	207.00	.189
HOTELLINGS	.01621	1.67735	2.00	207.00	.189
WILKS	.98405	1.67735	2.00	207.00	.189

UNIVARIATE F-TESTS WITH (1,208) D. F.

VAR.	HYPOTH. SS.	ERROR SS.	HYPOTH MS.	ERROR MS.	F	P-VALUE*
INV	.00035	.02840	.00035	.00014	2.54	.112
SVC	.04666	3.45043	.04666	.01659	2.81	.095

*Critical values(.05): F(2,207) = 3.04; F(1,208) = 3.89
*Critical values(.01): F(2,207) = 4.71; F(1,208) = 6.76

"AxCxD" could not be ignored, it would be difficult to interpret the interaction effect based on available data from this study.

5.3 GENERAL ANALYSIS

Recognizing that all the main effects were significant, measurements of the strength of association between the significant effects and the variance in the linear combination of the dependent variables were computed as a function of the Wilk's Lambda:

$$r^2 = 1 - \text{Wilk's Lambda}$$

Wilk's Lambda represents the proportion of variance not accounted for in the linear combination of the dependent variables, thus (1 - Wilk's Lambda) is the proportion of variance that is accounted for. A significant effect with high strength of association value (or small Wilk's lambda) contributes greatly to differences in measured performance. The results, as summarized in Table 15, indicated strong association between the combined dependent variables and the effects A, C and D , each accounting for approximately 90% of the variance in the combined dependent variables. The strength of association was much less for master scheduling strategy, implying that changes in master

Table 15: Strength of Association to Dependent Variables

Effect	Wilk's Lambda	Variance %	Correlation(r)
A	.02367	.98	.99
B	.88659	.11	.34
C	.09586	.90	.95
D	.13200	.87	.93
A BY D	.90772	.09	.30
C BY D	.13945	.86	.92
A BY C BY D	.88456	.12	.34

scheduling strategy would not affect distribution performance as much as the other three main effects.

Furthermore, comparing the strength of association of the interaction effect A x D with those of the main effects A and D suggested that the interaction effect A x D was relatively unimportant toward explaining variance in the data. Similar relation was observed for interaction effect A x C x D. Thus, one might discount the significance of interaction effects A x D and A x C x D, and conclude that inventory management policies significantly affect distribution performance. For the same reason, it would be desirable to examine the nature of interaction between effects C x D.

A preliminary examination of the cell means listed in Table 16 would suggest that higher service performance occurred when safety stock was positioned at upper echelon plant facility under low uncertainty environment, while positioning safety stock at the wholesaler facilities

Table 16: Basic Statistics on Treatment Groups

CELL MEANS AND STANDARD DEVIATIONS

VARIABLE .. LOG10(INV)

CASE	ABCD	MEAN	STD. DEV.	N
1	1111	3.512	.008	14
2	1112	3.509	.009	14
5	1211	3.521	.016	14
6	1212	3.516	.011	14
9	2111	3.391	.003	14
10	2112	3.390	.002	14
13	2211	3.394	.007	14
14	2212	3.392	.003	14
3	1121	3.608	.012	14
4	1122	3.529	.018	14
7	1221	3.614	.018	14
8	1222	3.539	.016	14
11	2121	3.501	.012	14
12	2122	3.401	.013	14
15	2221	3.511	.013	14
16	2222	3.407	.010	14

VARIABLE .. SVC^2

CASE	ABCD	MEAN	STD. DEV.	N
1	1111	.886	.108	14
2	1112	.918	.091	14
5	1211	.779	.181	14
6	1212	.818	.143	14
9	2111	.954	.032	14
10	2112	.958	.019	14
13	2211	.915	.079	14
14	2212	.942	.037	14
3	1121	.839	.145	14
4	1122	.835	.172	14
7	1221	.757	.207	14
8	1222	.687	.179	14
11	2121	.896	.124	14
12	2122	.826	.093	14
15	2221	.771	.148	14
16	2222	.761	.108	14

A: 1=PULL, 2=PUSH B: 1=CHASE, 2=LEVELLED C: 1=LOW CV, 2=HIGH CV D: 1=SSd, 2=SSp yielded higher service performance under high uncertainty environment. However, service variance and inventory performance failed to substantiate these observations. Further investigation of the interaction relationship between environmental uncertainties and safety stock positioning strategy might provide valuable information for inventory managers.

In order to understand the performance of each treatment group relative to other groups, multiple comparison techniques were employed to estimate the family confidence intervals for the comparison of various pairs of treatment means. At a .05 risk of making a Type I error, both Tukey's method and Scheffe's method identified three families of treatment groups with significantly different inventory performance. Figure 18 summarizes the findings. All groups in Family I are Push System, and all of Family III are Pull Systems, while there are a mixture of both systems in Family II. Both multiple comparison tests failed to distinguish service performance of various treatment groups.

In general, the results supported the MANOVA findings that inventory replenishment approach was significantly affecting distribution performance. However, high variance of service measurements might have caused difficulties in separating the treatment groups by

INVENTORY MEASURE...

TUKEY-HSD PROCEDURE (.05 LEVEL)

HOMOGENEOUS SUBSETS
(SUBSETS OF GROUPS, WHOSE HIGHEST AND LOWEST MEANS
DO NOT DIFFER BY MORE THAN THE SHORTEST
SIGNIFICANT RANGE FOR A SUBSET OF THAT SIZE)

```
                  C C C C C C C C C C C C C C C C
                  A A A A A A A A A A A A A A A A
                  S S S S S S S S S S S S S S S S
                  E E E E E E E E E E E E E E E E
                  1 0 1 1 1 1 1 0 1 0 0 0 0 0 0 0
                  0 9 4 3 2 6 1 2 5 1 6 5 4 8 3 7

SUBSET 1          ___________
SUBSET 2                      _________
SUBSET 3                        _________
SUBSET 4                              _____
SUBSET 5                                  ___
SUBSET 6                                      ___

                  FAMILY I   ¦FAMILY II       ¦FAMILY III
                  (Push)       (Mixed)        (Pull)

                  (Increase Inventory Level -----------> )
```

SCHEFFE PROCEDURE (.050 LEVEL)

HOMOGENEOUS SUBSETS
(SUBSETS OF GROUPS, WHOSE HIGHEST AND LOWEST MEANS
DO NOT DIFFER BY MORE THAN THE SHORTEST
SIGNIFICANT RANGE FOR A SUBSET OF THAT SIZE)

```
                  C C C C C C C C C C C C C C C C
                  A A A A A A A A A A A A A A A A
                  S S S S S S S S S S S S S S S S
                  E E E E E E E E E E E E E E E E
                  1 0 1 1 1 1 1 0 1 0 0 0 0 0 0 0
                  0 9 4 3 2 6 1 2 5 1 6 5 4 8 3 7

SUBSET 1          ___________
SUBSET 2                      ___________
SUBSET 3                        ___________
SUBSET 4                                _____
SUBSET 5                                      ___
                  FAMILY I   ¦FAMILY II       ¦FAMILY III
                  (Push)       (Mixed)        (Pull)

                  (Increase Inventory Level -----------> )
```

Figure 18: Multiple Comparison Tests Results

SERVICE MEASURE...

TUKEY-HSD PROCEDURE (.05 LEVEL)

HOMOGENEOUS SUBSETS
(SUBSETS OF GROUPS, WHOSE HIGHEST AND LOWEST MEANS
DO NOT DIFFER BY MORE THAN THE SHORTEST
SIGNIFICANT RANGE FOR A SUBSET OF THAT SIZE)

```
              C C C C C C C C C C C C C C C C
              A A A A A A A A A A A A A A A A
              S S S S S S S S S S S S S S S S
              E E E E E E E E E E E E E E E E
              0 0 1 1 0 0 1 0 0 0 1 1 0 1 0 1
              8 7 6 5 5 6 2 4 3 1 1 3 2 4 9 0

SUBSET  1     _________________
SUBSET  2       _______________________
SUBSET  3           _____________________
SUBSET  4               _____________________
```

FAMILY A

(Increasing Service Level ---->)

SCHEFFE PROCEDURE (.050 LEVEL)

HOMOGENEOUS SUBSETS
(SUBSETS OF GROUPS, WHOSE HIGHEST AND LOWEST MEANS
DO NOT DIFFER BY MORE THAN THE SHORTEST
SIGNIFICANT RANGE FOR A SUBSET OF THAT SIZE)

```
              C C C C C C C C C C C C C C C C
              A A A A A A A A A A A A A A A A
              S S S S S S S S S S S S S S S S
              E E E E E E E E E E E E E E E E
              0 0 1 1 0 0 1 0 0 0 1 1 0 1 0 1
              8 7 6 5 5 6 2 4 3 1 1 3 2 4 9 0

SUBSET  1     _________________________
SUBSET  2       _____________________________
```

FAMILY A

(Increasing Service Level ---->)

Figure 18 (continue)

service performance. In response to that, additional analyses, including nonparametric tests, were performed.

Since the experimental design incorporated different levels of variance for different treatment groups, in order to control the within treatment variance, the data set was split, according to uncertainty levels, and the MANOVA procedure repeated on the two data subsets.

The data subset for low uncertainty conditions grossly violated the homogeneity of variance assumption, despite all efforts to transform the data set. The major reason was due to the much higher variance in the performance measures of two treatment groups - cases 5 and 6, as shown in Table 16. Thus the significance level of an effect should be much lower than .05 to be acceptable as having an actual .05 significance level. MANOVA indicated that only main effects A and B were significant at $p<.01$. Scheffe's Multiple Comparison, being unaffected by heteroscedasticity, separated the eight treatment groups into two families by the inventory measure. Figure 19 shows all Push Systems in a family (Family I), and Pull Systems in a second family (Family II). Again all groups were classified into a single family by the service measurement.

The data set under high uncertainty satisfied the homogeneity of variance assumption, and the main effects A, B, and D were significant at $p<.01$. However, neither A nor D were significant for service measurement (SVC)

```
VARIABLE  INV
                 LOW UNCERTAINTY    HIGH UNCERTAINTY
                 (LO-- INV -->HI)   (LO-- INV -->HI)
                 C C C C C C C C    C C C C C C C C
                 A A A A A A A A    A A A A A A A A
                 S S S S S S S S    S S S S S S S S
                 E E E E E E E E    E E E E E E E E
                 1 0 1 1 0 0 0 0    1 1 1 1 0 0 0 0
                 0 9 4 3 2 1 6 5    2 6 1 5 4 8 3 7

TUKEY PROCEDURE
SUBSET  1        _______            ___
SUBSET  2                _____          ___
SUBSET  3                  _____            ___
SUBSET  4                                       ___

SCHEFFE PROCEDURE
SUBSET  1        _______            ___
SUBSET  2                _______        ___
SUBSET  3                                 ___
SUBSET  4                                   ___
SUBSET  5                                       ___

FAMILY          ¦   I   ¦   II    ¦ III¦  IV   ¦ V ¦
                 (PUSH)   (PULL)  (PUSH) MIXED (PULL)


VARIABLE  SVC
                 LOW UNCERTAINTY    HIGH UNCERTAINTY
                 (LO-- SVC -->HI)   (LO-- SVC -->HI)
                 C C C C C C C C    C C C C C C C C
                 A A A A A A A A    A A A A A A A A
                 S S S S S S S S    S S S S S S S S
                 E E E E E E E E    E E E E E E E E
                 0 0 0 1 0 1 0 1    0 0 1 1 1 0 0 1
                 5 6 1 3 2 4 9 0    8 7 6 5 2 4 3 1

TUKEY PROCEDURE
SUBSET  1        ___                _____________
SUBSET  2          _______            _____________
SUBSET  3            ___________

SCHEFFE PROCEDURE
SUBSET  1        _________          _______________
SUBSET  2          _____________

FAMILY                   A                 B
```

Figure 19: Multiple Comparison of Split Data

under univariate-F test. From Figure 19, multiple comparison with Tukey's approach yielded four families, while Scheffe's approach identified three families. The families could be characterized, in order of decreasing inventory performance (or increasing average inventory level): Push System with Safety Stock at plant (SSp), both Push System with Safety Stock at distribution facility (SSd) and Pull System with SSp, and lastly the family of Pull System with SSd. All groups were not significantly different from one another under service measurement.

Further analysis using the nonparametric Friedman test (Conover, 1980) yielded a testing statistic (T4) of 49.1 for simultaneous consideration of both inventory and service measurements. The Freidman test statistics exceeded the critical value of 25, obtained from the .95 quantile of chi-square random variable with 15 degrees of freedom, and therefore supporting the hypothesis that at least one of the treatments tends to yield higher performance than at least one other treatment. Repeating Friedman test on each of the inventory and service performance measures yielded test statistics of 192 and 65.1 respectively, both showing significant difference among performance of some of the treatment groups.

A multiple comparison method (Conover, 1980) was used to detect individual paired differences among treatment groups. Table 17 summarizes the computed test

Table 17 Nonparametric Multiple Comparison Test Statistics

CASES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	27	94	43	73	45	123	121	144	150	41	43	89	127	48	2
2		0	121	70	100	73	150	148	117	123	14	16	62	100	75	29
3			0	51	22	49	29	27	238	244	135	137	183	221	46	93
4				0	30	3	80	78	187	193	84	86	132	170	5	42
5					0	27	50	49	217	223	113	115	161	199	25	71
6						0	77	76	190	196	86	88	134	172	3	44
7							0	3	267	273	163	165	211	249	75	121
8								0	265	271	162	164	210	248	73	120
9									0	6	104	102	56	18	192	146
10										0	110	108	62	24	198	152
11											0	2	48	86	89	42
12												0	46	84	91	44
13													0	38	137	90
14														0	175	128
15															0	47
16																0

(* Treatment pairs significantly different at .05 level if corresponding test statistic > 116)

MAIN EFFECT	TREATMENT PAIRS
A	(1,9)* (2,10)* (5,13)* (6,14)* (3,11)* (4,12) (7,15) (8,16)*
B	(1,5) (2,6) (9,13) (10,14) (3,7) (4,8) (11,15) (12,16)
C	(1,3) (2,4) (5,7) (6,8) (9,11) (10,12) (13,15)* (14,16)*
D	(1,2) (5,6) (9,10) (13,14) (3,4) (7,8) (11,12) (15,16)

statistics for pairwise comparisons of treatment groups, with critical value equal to 116 at a .05 significant level. Significant differences between inventory management policies were observed in six out of eight of the treatment pairs. Uncertainty levels were found to significantly affect Push Systems, but not significant with Pull Systems. This indicated that Pull and Push Systems might have different tolerance level toward changes in environmental uncentainties. Lastly, neither master production scheduling strategy nor safety stock positioning were significant factors. This finding is consistent with the weak measures in strength of association of these two effects.

5.4 GRAPHICAL PRESENTATION

The overall experimental results are not immmediately clear from the somewhat fragmented evidences from the various analyses. The research results could be better understood through a visual presentation of the relative effectiveness of various treatment groups. However, it would be awkward to present the data through the traditional inventory-service tradeoff curves, both due to the large number of treatment groups, and the broad range of output measurements. Besides, the inventory-service curves could not show the degree of variance in data, which is very important for the current study. Since in practice, common performance measures would include average inventory level, average service level, and service reliability, but not inventory level variability, a graphical approach for presenting the experimental results was developed.

Figure 20 shows a graph which represents inventory measurements on the vertical axis, and a series of multiple graphs for service measurements of multiple cases across the horizontal axis. The entries in the graphs are ranges of service performance for each of the sixteen treatment groups, at the corresponding average inventory levels.

The transformed variable LOG10(INV) is represented on the vertical axis of Figure 20. The transformed variable has the advantage of spanning a shorter range and has lower variance than the original data, and therefore a more suitable variable for graphs. The horizontal axis represents the squared service level which allows wider spreading of service range for better visual effects on graph. However, readers should be aware of the nonlinear scales of the graph. For example, a .01 shift at the bottom of the vertical scale represents 57 inventory units, while the same shift at the top of the scale represents 90 units. Similarly, a shift of .1 on the left side of the horizontal scale

```
3.615 LGO(INV)    ||           |.......*....>|           |
3.610I|           ||           ||           ||           |
3.605I|           ||           ||           ||           |
3.600+|  <.....*..>|           ||           ||           |
3.595I|           ||           ||           ||           |
3.590I|           ||           ||           ||           |
3.585I|           ||           ||           ||           |
3.580I|           ||           ||           ||           |
3.575I|           ||           ||           ||           |
3.570I|           ||           ||           ||           |
3.565I|           ||           ||           ||           |
3.560I|           ||           ||           ||           |
3.555+|           ||           ||           ||           |
3.550I|           ||           ||           ||           |
3.545I|           ||           ||           ||           |
3.540I|           ||           ||           ||......*.....>
3.535I|           ||           ||           ||           |
3.530I|           || <......*..>|           ||           |
3.525I|           ||           ||           ||           |
3.520I|           ||           |<________*___>|           |
3.515I|           ||           ||           ||  <----*--->
3.510I|   <____*_>|   <__*_>| <::::*::::>|           |
3.505I|           ||           ||           ||           |
3.500+|   <::::*:>|           ||           ||           |
3.495I|           ||           ||           ||           |
3.490I|           ||           ||           ||           |
3.485I|           ||           ||           ||           |
3.480I|           ||           ||           ||           |
3.475I|           ||           ||           ||           |
3.470I|           ||           ||           ||           |
3.465I|           ||           ||           ||           |
3.460I|           ||           ||           ||           |
3.455I|           ||           ||           ||           |
3.450+|           ||           ||           ||           |
3.445I|           ||           ||           ||           |
3.440I|           ||           ||           ||           |
3.435I|           ||           ||           ||           |
3.430I|           ||           ||           ||           |
3.425I|           ||           ||           ||           |
3.420I|           ||           ||           ||           |
3.415I|           ||           ||           ||           |
3.410I|           ||           ||           ||           |
3.405I|           ||           ||           ||  <:::*::::>
3.400+|           ||   <:::*::>|           ||           |
3.395I|           ||           ||    <==*=>|           |
3.390I|       <*=|        <*=|           ||      <=*>  2
3.385I|-+---------||-+---------||-+---------||-+---------|SVC
        .5       1. .5       1. .5       1. .5       1.
PULL/HI  CASE 3<..>   CASE 4<..>   CASE 7<..>   CASE 8<..>
PULL/LO  CASE 1<__>   CASE 2<__>   CASE 5<__>   CASE 6<__>
PUSH/HI  CASE11<::>   CASE12<::>   CASE15<::>   CASE16<::>
PUSH/LO  CASE 9<==>   CASE10<==>   CASE13<==>   CASE14<==>
         SSd/CHASE    SSp/CHASE    SSd/LEVEL    SSp/LEVEL
      (< >  2 STANDARD DEVIATION HALF WIDTH SERVICE RANGE
       *    REPRESENTS AVERAGE SERVICE LEVEL)
```

Figure 20 Performance of Treatment Groups corrresponds to 7% change in actual service level, while the same shift represents 5% on the right side of the graph. The plotted service range represents a spread of two standard deviation on either side of the average service level, which is represented by the asterisk.

In Figure 20, treatment groups under high environmental uncertainties are represented by single and double dots, while treatments under low uncertainties are represented by single and double dashes. Figure 20 clearly shows lower average inventory levels for Push Systems than Pull Systems under similar environmental conditions, and that Push Systems provide more reliable and higher service level than Pull Systems. The above observations are consistent with current beliefs that Push Systems tend to perform better than Pull Systems.

However, Figure 20 also shows Pull Systems to be more stable in service performance than Push Systems. For example, Case 14 and Case 16 represent a Push System that experiences a 11% drop in average service level, and more than 200% increase in variability of the service performance, with increase in uncertainty levels. The Pull System undergoing similar environmental changes suffers only 6% decrease in average service level, and less than 50% increase in service variability. In general, the average service performance of Push Systems is observed to deteriorate almost twice as fast as Pull Systems when environmental uncertainties increase.

Another noticeable difference between Push Systems and Pull Systems is the much higher average inventory levels of Pull Systems. This can be explained through differences in replenishment rules between the two systems. Push Systems emphasize tight inventory control but impose little restriction on order sizes. On the other hand, a Pull System employing the min/max criterion requires the minimum order quantity to be equal or exceeding the difference between the maximum level and the reorder point. Therefore replenishment order is sometime not issued for some review period. In order to ensure inventory availability, the reorder point commonly represents demands during lead time and review period. Inventory positions for Push Systems immediate after inventory review equal demands during lead time and review period. Following inventory review, inventory position for a Pull System is between the reorder point and the maximum level, hence Pull Systems carry more inventory than Push Systems on the average.

However, the additional inventory carried by Pull Systems provided additional protection against environmental uncertainties, therefore the more stable service performance of Pull Systems.

Further observations suggested that inventory systems under high uncertainty environment have higher inventory levels. Increased safety stock level partially accounted for the higher inventory level. This was evidenced in that treatment groups like case 4 and case 8, which positioned safety stock at production plant, suffered less increment in distribution inventory level with increased uncertainty levels, than case 3 and case 7, which positioned safety stock at distribution facilities. Increased stockouts, as reflected by lower service level, was the second factor contributing to the increased inventory level under high uncertainties.

Inventory systems supported by production facility adopting a chase MPS experienced lower inventory levels, and better (or comparable) service performance than those supported by levelled production schedules, although the difference was negligible for Push Systems under low uncertainty environments.

Lastly, Push Systems under low environmental uncertainties, as indicated in Figure 20, demonstrated simultaneous high service performance, and very low inventory as so often acclaimed to be the benefits of Push Systems. However, one should also be reminded of the fast deterioating performance of Push System under high environmental uncertainties as discussed previously.

Overall, Figure 20 supports the testing results of the first two hypotheses, that production strategy and inventory management approach significantly affect distribution performance. It fails to provide a clear evidence to reject the third hypothesis that safety stock position strategy is independent of inventory management approaches, although MANOVA significance test rejected the hypothesis. Lastly, in agreement with hypothesis testing results, there is no evidence to reject hypothesis four that the effect of uncertainties is independent of inventory management approach.

CHAPTER VI

CONCLUSIONS

6.0 INTRODUCTION

This chapter relates research findings to the general body of knowledge in distribution inventory management. The chapter first addresses results of hypothesis testings in relation to the research questions. Then the scope of discussion is broaden to include systems design considerations for distribution inventory management. The chapter ends with proposal of managerial guidelines, and suggestion for future research.

6.1 IMPLICATION OF RESEARCH FINDINGS

In recent years, the just-in-time concept has been gaining increasing momentum in the manufacturing and procurement segments of distribution channels. In a just-in-time production environment, systematic removal of excess inventory is gradually becoming a reality in many firms. Progressive elimination of buffer stock could expose distribution operations to fluctuations in production activities. A major objective of this study was to investigate whether production activities affect distribution performance under conditions of limited buffer stock availability and limited production capacity.

This research has investigated a hypothetical production-distribution channel system, in which the production facility produced inventory "just-in-time" for fullfilling anticipated orders from two wholesaler facilities. Plant inventory was usually maintained at a level sufficient to satisfy the projected shipment quantity for the upcoming week, except during low demand seasons when additional inventory was accumulated as anticipation stock. Analysis of simulation results through MANOVA technique showed that a chase master production scheduling strategy (MPS) contributed to significantly better distribution performance than a levelled master scheduling strategy. Specifically, implementation of a chase MPS consistently yielded lower average distribution inventory level as well as higher and more reliable service at lower echelon facilities, regardless of the distribution inventory policies and level of environmental uncertainties.

However, more conservative tests such as Tukey's multiple comparison test, Scheffe's multiple comparison test, and the nonparametric Friedman test, failed to provide sufficient evidence to substantiate the significant effect of MPS strategies at less than 5% risk of drawing the wrong conclusion. Moreover, weak strength of association between MPS strategy and distribution performance indicated that only a small fraction of the performance differences between Push and Pull Systems could be attributed to different scheduling strategies.

Hence, no general conclusion can be made concerning the effect of master scheduling policy on distribution performance, although if master scheduling strategy indeed significantly affect distribution performance, it is relatively less important than elements of inventory policy, uncertainties, and safety stock strategies being investigated. However, one should not discount the potential influence of production scheduling strategy on distribution performance. Current research has examined only a limited subset of the supply conditions, particularly with a production lead time longer than the replenishment lead time. Additional research may examine the effect of MPS under an environment with a short production cycle relative to the replenishment lead time.

The general implication for distribution managers is that a supplier who has flexible production schedules is potentially more capable of responding to changing demand patterns, thus supporting higher level of service performance at distribution facility without substantial increase in distribution inventory level. This is especially important when the manufacturer maintains low levels of finished products. However, the scheduling strategy of a supplier should not be overemphasized in distribution inventory decision making. Until stronger evidence is available to support the significance of master scheduling strategies under broader circumstances, the recommendation is for distribution inventory managers to consider master scheduling strategy as a secondary, but important factor in distribution inventory decisions.

On the other hand, from a systems point of view, this research suggests that converting from a levelled production strategy to a chase scheduling strategy would not be an effective approach for improving distribution performance, especially under uncertain environments.

Numerous reports and discussions in literature have compared performance of Push Systems and Pull Systems (Martin 1983; Ritzman and Krajewski, 1983; Dixon, 1985). However, extant literature tends to describe Push Systems and Pull Systems under different environments, and failed to compare performance of these systems under controlled experimental conditions, especially in the investigation of factors that contribute to the success of inventory systems. This research is unique in that special efforts have been made to distinguish decision factors and resource endowments from inventory replenishment logics. The research design controlled and imposed common assumptions on both the Push System and the Pull system. Examples are weekly inventory review, availability of dynamic forecasts, statistically forecastable demand, replenhishment lead time, and backordering of stockout items at production facility. Such control measures ensure similar inventory control activities and information processing activities between the Push and the Pull Systems. Therefore, the performance evaluation of such inventory management systems could be narrow down to inventory holding cost, and service measurements. In addition, detectable performance difference could be attributed to differences in inventory management approaches.

This study found significant performance differences between two groups of inventory systems that differ primarily in the inventory replenishment decision logic, namely independent replenishment decisions compared to centralized inventory allocation. In all cases investigated in this research, Push Systems performed better than Pull Systems with respect to both inventory and service measures. These results supplement previous findings (Closs and Law, 1983) that Pull Systems with perpetual inventory review, showed worse performance than Push Systems with weekly review, but performed better than Push Systems with biweekly review. Both review period and order quantities have been controlled in the current study.

The immediate conclusion is that centralized inventory decision is more effective than decentralized inventory decision, provided all inventory control and replenishment activities are the same.

The research implication is that under environments with limited inventory availability, like just-in-time production environments, the Push System offers more potential for achieving high level of distribution inventory and service performance, for the reason that it allows better allocation of limited inventory. There is very strong indication that the Push System yielded lower distribution inventory levels than the Pull System. The implication is that centralized inventory decisions should be seriously considered by managers who are concerned about controlling distribution inventory investments under tight inventory supply conditions.

Moreover, the Push System in the current study utilized a simple inventory allocation rule at the central facility, without the assistance of a sophisticated information system. Therefore the initial benefits of adopting the Push System do not require installation of a sophisticated planning system. To the distribution manager, this has strong implication for the need to reevaluate the potential benefits of Push Systems. It is extremely important for one not to confuse Push Systems, with computerized inventory management systems that employ Push replenishment logic. The latter assist managers to perform, otherwise, tasks with unmanageable details, but could not in anyway replace good fundamental knowledge required for selecting the correct inventory management approach for the specific applications. For many less complex business environments, distribution manager may find the Push inventory management approach benefitial, without the need for expensive computer systems.

However, readers should keep in mind the simple system configuration represented by the conceptual model. Generalization of research findings should be made with caution until additional comparative information for more complex systems becomes available. Other factors such as human behavior, strategic considerations, cooperative spirits among channel members, and alternative performance criteria may affect the relative performance of the Pull and the Push Systems.

If one concerns about product availability, and service reliability, Figure 20 shows that Push System offers very low inventory level and extremely high service performance under low uncertainty environment, as often reported in the literature. However, performance of the Push System under low environmental uncertainty should not be generalized to high uncertainty enivronments. Research findings showed substantial decrease in the service level of the Push System, accompanied by an increase in service variability with increased uncertainty. Both the Push System and the Pull System were equally affected by high environmental uncertainties. There was insufficient evidence to show that environmental uncertainties would have different effects on the two systems.

The general conclusion is that effects of environmental uncertainties cannot be removed by merely changing inventory approach. High uncertainties in lead time and demand decrease distribution performance, regardless of inventory management approach being adopted.

The managerial implication is that when the managerial problem is low service performance because of high variability of demand and lead time around predicted values, changing inventory management approach from a Pull System to a Push System will not provide significant improvements for distribution performance, especially service performance. Figure 20 shows that adopting a Push System for inventory management has the initial benefit of lowering distribution inventory level, but contributes very little toward service improvement. However, when the variability of evironmental factors can be reduced, either through better forecasting, or better demand and lead time management, a Push System offers good potential for achieving high service performance.

Moreover, when managers consider adopting a Push System, the forecastability of demand and lead time for the reference successful system should be compared with the target system, thus reducing the risk of unacceptable system performance after implementation of a Push System.

Lastly, this research found safety stock positioning strategy significantly affecting the distribution inventory level, but not the distribution service performance. Figure 20 shows a relatively higher level of distribution inventory when safety stock is positioned at distribution facilities. The increases in inventory levels can be explained by the presence of various amounts of safety stock at wholesaler facilities. On the other hand, the increase in inventory level is slightly higher under the Push System, than under Pull System. Although interaction of safety stock positioning strategy and inventory approach is significant, there is insufficient information to explain in detail the nature of the interaction effect.

The research finding of insignificant effect of safety stock strategy on service performance disagreed with previous research findings by Cook (1980), who concluded that safety stock position can significantly affect customer service level in a serial channel system. There are three possible explanations. Firstly, the previous research assumed single lower echelon member with infinite inventory supply. The current research considered two lower echelon members competing for a limited supply of inventory. Thus safety stock at production facility might assumed an equally important role in protection against supply uncertainties as its role in protection against lead time uncertainties when positioned at distribution facilities. Secondly, current research created backorders when there was stockout at production facility. The additional backorder shipments, which were not allowed in the previous research, might interact with lead time uncertainties, thus changing the need for protection against lead time uncertainties at distribution facilities. Lastly, the previous research investigated a fixed order quantity policy while the current study investigated Min/Max policy and Push policy. In addition, introduction of a stochastic production lead time into the simulation model, contributed to high variance in system performance observed in the current study, might have caused the different findings in the current study.

The research conclusion is mixed. On one hand, positioning safety stock at a given facility inflated the inventory level at the facility. On the other hand, the higher level of inventory at lower echelon facilities failed to provide significant service improvement. It appeared that under a limited inventory availability situation, locating safety stock at lower echelon facilities tended to draw inventory to distribution facilities at the wrong time, resulting in confusion of priority at the central facility. The effect of positioning safety stock at the distribution facility was more stockout at the central facility.

The managerial implication is that under limited inventory supply conditions, holding safety stock at lower echelon facilities instead of the central supply location might increase distribution inventory levels without the expected benefit of improvement in service level. Results from the current research suggest that protection against supply uncertainties at the upper echelon level may be as important as protection against lead time and demand variance at the lower echelon level in distribution systems described by the conceptual model. Further investigation of the role of safety stock in multiechelon distribution systems should include the relationship of supply and demand uncertainties in safety stock decisions.

6.2 IMPLICATION FOR INVENTORY SYSTEM DESIGN

This section integrates current research findings into the broader design considerations of distribution inventory systems. Although the research findings are based on the simulation of specific situations, the conditions are representative enough to infer upon more general management considerations.

Recent trend in just-in-time production indicates the beginning of progressive efforts to reduce inventory stocks. The consequence is the continuous lowering of buffer stock at the productive-distribution interface to below a comfortable level for many distribution inventory managers. However, just-in-time concepts also advocate flexibility in production operations to accompany inventory reduction. Current research indicated that flexible production operations are preferable in a tightly-coupled production-distribution environment. The implication for distribution manager is that when manufacturer can successfully and economically shift from rigid, levelled production scheduling practice to more flexible, market chasing production scheduling with backordering policy, the consequence improvement in distribution performance can potentially compensate for reduction in buffer stock, regardless of the distribution inventory management approach. However, carefully designed inventory management systems, and accurate demand information are even more important than flexible production schedules, which have relatively small influence on distribution effectiveness. Therefore, distribution managers should devote more attention to improving inventory systems design and demand information management, than concerning about the effects of just-in-time production management.

For many years, distribution inventory management have been dominated by Pull Systems, which have been recognized as ineffective in managing multiechelon systems. Recently, Push Inventory Planning Systems, which integrated Push replenishment logic with information systems, have been proposed as alternatives for managing distribution systems. Despite the demonstrated benefit of Push Inventory Planning System in reducing inventory level, many distribution systems are still managed by Pull Systems. Some obstacles have been the lack of understanding of Push Inventory Planning Systems. High installation costs, and reported failures due to improper implementation of such systems also thwarted interest in the systems. However, one should not discount Push replenishment logic as an attractive alternative approach to managing distribution inventory.

Current research findings showed that substantial reduction in distribution inventory level were achievable by replacing a Pull System with a Push System, without a sophisticated information system. For example, the Push System being simulated had access to monthly dynamic forecast information, and weekly projected requirements at each distribution facility. Thus the information processing requirements were no more than processing independent replenishment orders under the Pull System.

However, using the Push System alone contributed little toward achievement of high service performance goals. This research showed that reducing environmental uncertainty is necessary for the Push System to achieve the coveted high service and low inventory performance.

The implication for systems design is that initial benefits of Push Systems in reducing distribution inventory levels can be achieved through improving communication between echelon levels, and the establishment of centralized inventory allocation criteria. Changes in communication could include periodic transmission to production facility, inventory status and demand forecast at each lower echelon facility, in replacement for replenishment orders under Pull Systems. At the same time, it may be desirable to replace replenishment order cost by communication service charge, to discourage the practice of irregular and lumpy replenishment requests. Inventory allocation criteria approved by lower echelon members would also be desirable to ensure priorities of allocating limited inventory stock, and the overall credibility of the Push System. Establishment of communication channel for confirmation of allocation priority may also be desirable.

While Push Systems provide better service performance than Pull systems, there is no indication that either Pull System or Push System would offer significantly advantageous service performance under high environmental uncertainties. Achievement of specific service targets would require trading off with cost of improving information quality, through better forecasting or better information processing capability.

An alternative to monitoring the environment is to reduce complexity and variability of environment. Recent changes in the deregulated transportation industry provide opportunities for distribution managers. More and more carriers are willing to negotiate for committed shipping business by accepting greater responsibility in assuring the reliability of transportation service. Previous research (Aggerwal and Dhavale, 1975) indicated that reduction of lead time uncertainties contributed more to distribution performance than reducing demand uncertainties. The implication is that distribution manager could take advantage of the opportunity to improve distribution service performance by reducing lead time variance.

In designing distribution inventory management system, managers should weigh the benefits of investing in quality forecast information, compared with the benefits of information systems, or the effectiveness of demand and lead time management, for the specific application.

Lastly, current research suggests that distribution manager should give equal consideration for service variability, other than average service level, in evaluating performance of distribution inventory systems.

6.3 RESEARCH CONTRIBUTIONS

This study represented the first extensive effort to investigate inventory management at the production - distribution interface. Previous studies either addressed the inventory management problem as a functional issue of distribution management (Cook, 1980; Dauermeyer et al, 1981), or as an issue of production management (Krajewski et al, 1983); or some authors focused their attention to a specific inventory management approach (Martin, 1983; McCollum, 1981). This study adopted a systems view in looking at the inventory management problem, giving equal considerations for production activities as well as distribution activites. Through detailed representation of all major production and distribution activities, the current research investigated effects of basic managerial decision factors toward effectiveness of production - distribution systems.

Moreover, this study conducted a systematic review of the characteristics of Pull Systems and Push Systems, and compared the performance of the two major inventory management approaches under controlled environments. It was recognized that one cannot distinguish a Pull System from a Push System in a simplistic manner, but elaborate statements of the assumptions and inventory decision factors and parameters becomes necessary. With a poliferation of inventory models, each adopting different factors and parameter values, information on the effects of factors and parameter values on distribution performance should be more useful than performance information on individual inventory model. The ability to understand the factors contributing to effective inventory management systems is invaluable for distribution managers who must select and design the management tools for specific applications. Through controlled experimental environment, this study isolated the effects of basic factors such as uncertainties, inventory management approach, master scheduling policy, and safety stock positioning strategy, from effects of factors such as order quantity, inventory review frequency, information quality, inventory supply flow, and data processing capability.

Lastly, this research demonstrated the importance of measuring variance of performance measures, which is often neglected in evaluating distribution management systems.

Limitation of time and cost were obvious constraints on the scope of this research. Other related problems include transportation economy, impact of information technology and special operational options such as expediting and transshipment have not been fully addressed.

Moreover, the conceptual model restricts the general research conclusion to similar distribution channel system. However, insight from this research provides general guidelines through which more detailed analysis of specific inventory policies can be performed. As Wagner has suggested, integrative analysis can help to limit the number of high level decision options to a select and attractive few. This will permit application of the now familiar lower level model-building approaches to refine the analyses as needed (Wagner,1980).

6.4 FUTURE RESEARCH

The current research suggested the potential influence of master production scheduling strategy on distribution performance. The relatively long production lead time, compared with the replenishment lead time, might have dampened the effect of master scheduling. When the production lead time is shorter than the replenishment lead time, master scheduling may have stronger influence on distribution performance. Another factor could be the partial shipment and backordering policy at the production facility, making the timely availability of products at the production facility not very important. Investigation of these factors would provide better understanding of the role of production policies in distribution management.

Although current study reviewed the significance of interaction effects between safety stock strategy, inventory management approaches, and uncertainties, the relationships between these factors could not be fully explained through data collected. Further investigation of these interactive effects would be important for effective deployment of safety stock inventory.

APPENDICES

APPENDIX A

Logic Flow Summary of Simulation Model

The SPSF simulator consists of four modules - forecasting, production, event processor, and report generator. The first two modules have been enriched, especially with the addition of numerous production activities. The event processor has been retained without modification, and the report generator has been modified for generation of more detail reports in condensed formats. Another additional feature is interactive reporting options, allowing the simulation user to preview time series data before clearing statistics, and generating data for steady state analysis. The logic flow diagrams in this section reflect the enriched modules for forecasting and production activities, activity attributes, and activity priorities.

Table A1: EVENTS AND THEIR ATTRIBUTES

CODE	EVENT	UNIT INVOLVED	FREQUENCY	LOCATION
1	RCEIPT	ORDER	VARIABLE	WHOLESALER
2	ORDFIL	PRODUCT	DAILY	WHOLESALER
3	FORCTD	PRODUCT	WEEKLY	WHOLESALER
4	INVMGT	PRODUCT	WEEKLY	WHOLESALER
5	FORCTP	PRODUCT	WEEKLY	PLANT
6	PRDSCH	PRODUCT	VARIABLE	PLANT
7	PRODUC	PRODUCT	DAILY	PLANT
8	INVCUM	PRODUCT	DAILY	PLANT
9	BCKORD	ORDER	VARIABLE	PLANT
10	ORDPR	ORDER	VARIABLE	PLANT
11	REPORT			
12	END			
13	START			
14	CLEAR			

Table A2: ORDER OF OCCURENCE OF EVENTS IN EACH SIMULATED DAY

EVENT	FUNCTION	PRIORITY	SCHEDULED BY
RCEIPT	Arrival of shipment at wholesaler facility	20	ORDPR/BCKORD
ORDFIL	Processing of customer order at wholesaler facility	10	ORDFIL *
FORCTD	Demand forecast updating at wholesaler facility	30	INVMGT
INVMGT	Inventory management at wholesaler facility	40	INVMGT *
FORCTP	Demand forecast updating at production facility	50	PRDSCH
PRDSCH	Master production scheduling at production facility	60	PRDSCH *
PRODUC	Production rate update	70	PRODUC *
INVCUM	Finished goods inventory receipt at production faciltiy	80	INVCUM *
BCKORD	Backorder processing (only if backorder exist)	90	INVCUM
ORDPR	Order proocessing at producitonfacility/ backorder creation	100	INVMGT
REPORT	Output of collected data	200	
END	End simulation	500	
START	Start simulation	1	
CLEAR	Clear data statistics	5	

* Events scheduled during initialization

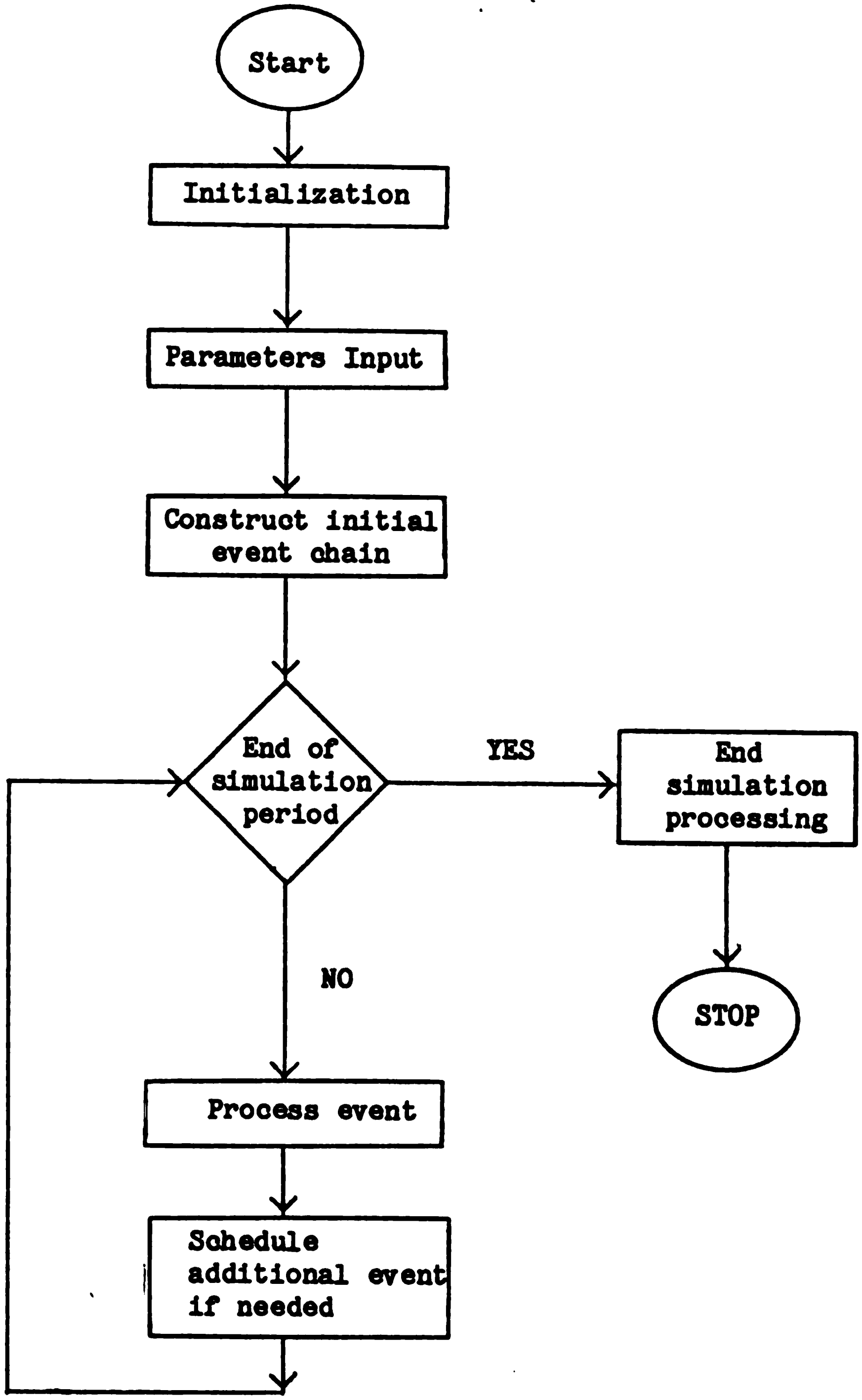


Figure A1: SIMULATOR LOGIC FLOW

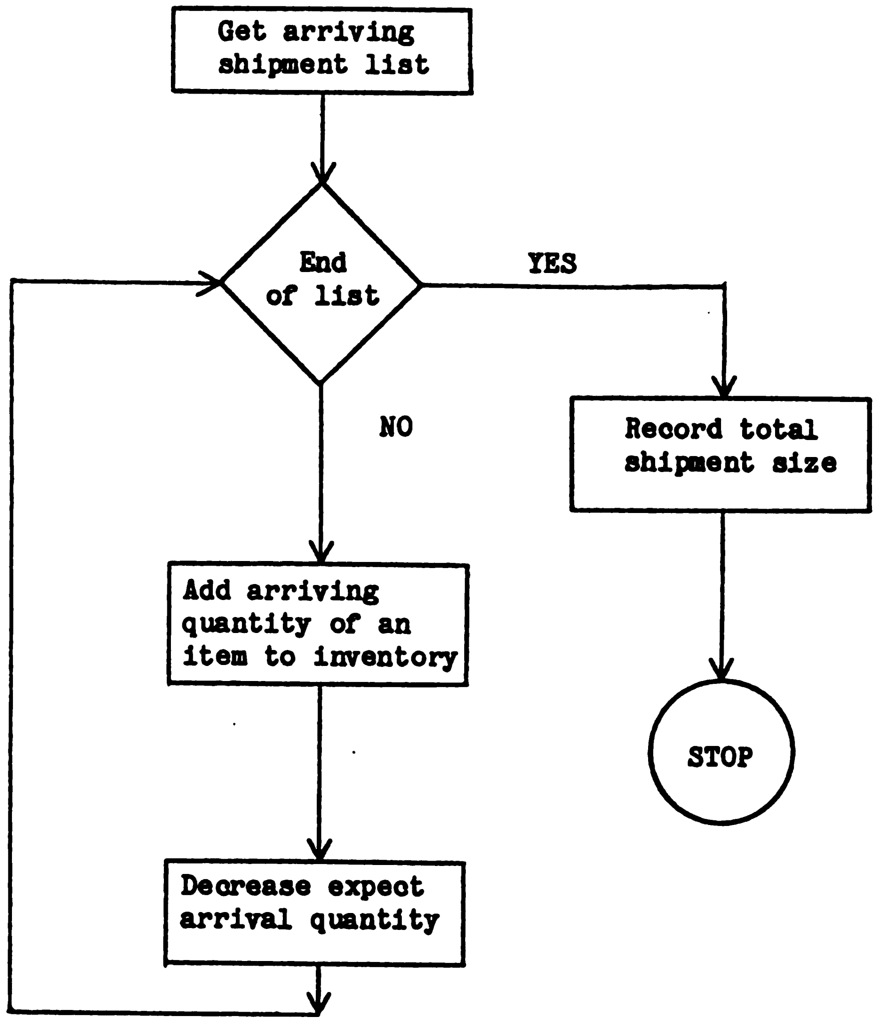


Figure A2: EVENT LOGIC FLOW - RCEIPT

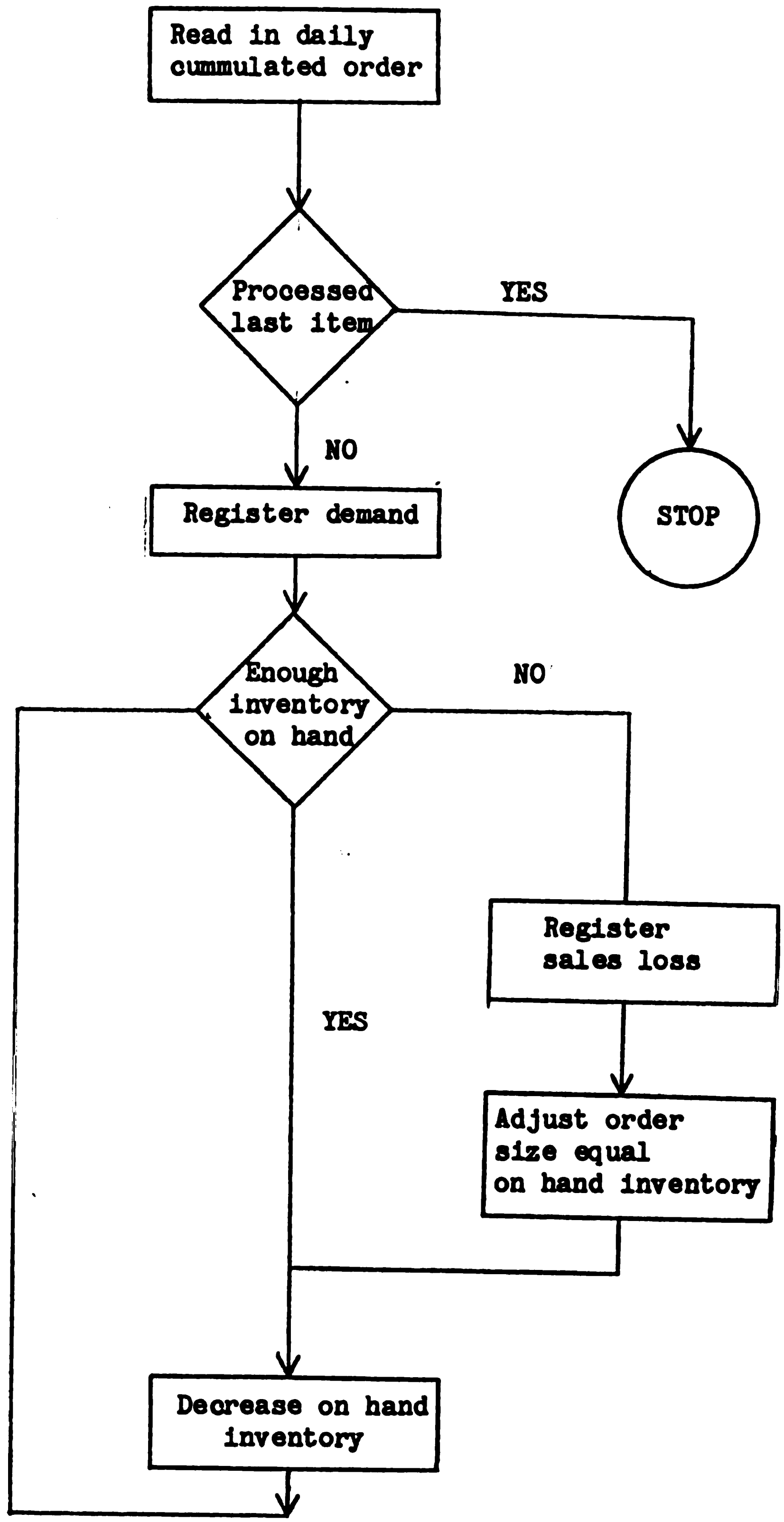


Figure A3: EVENT LOGIC FLOW - ORDFIL

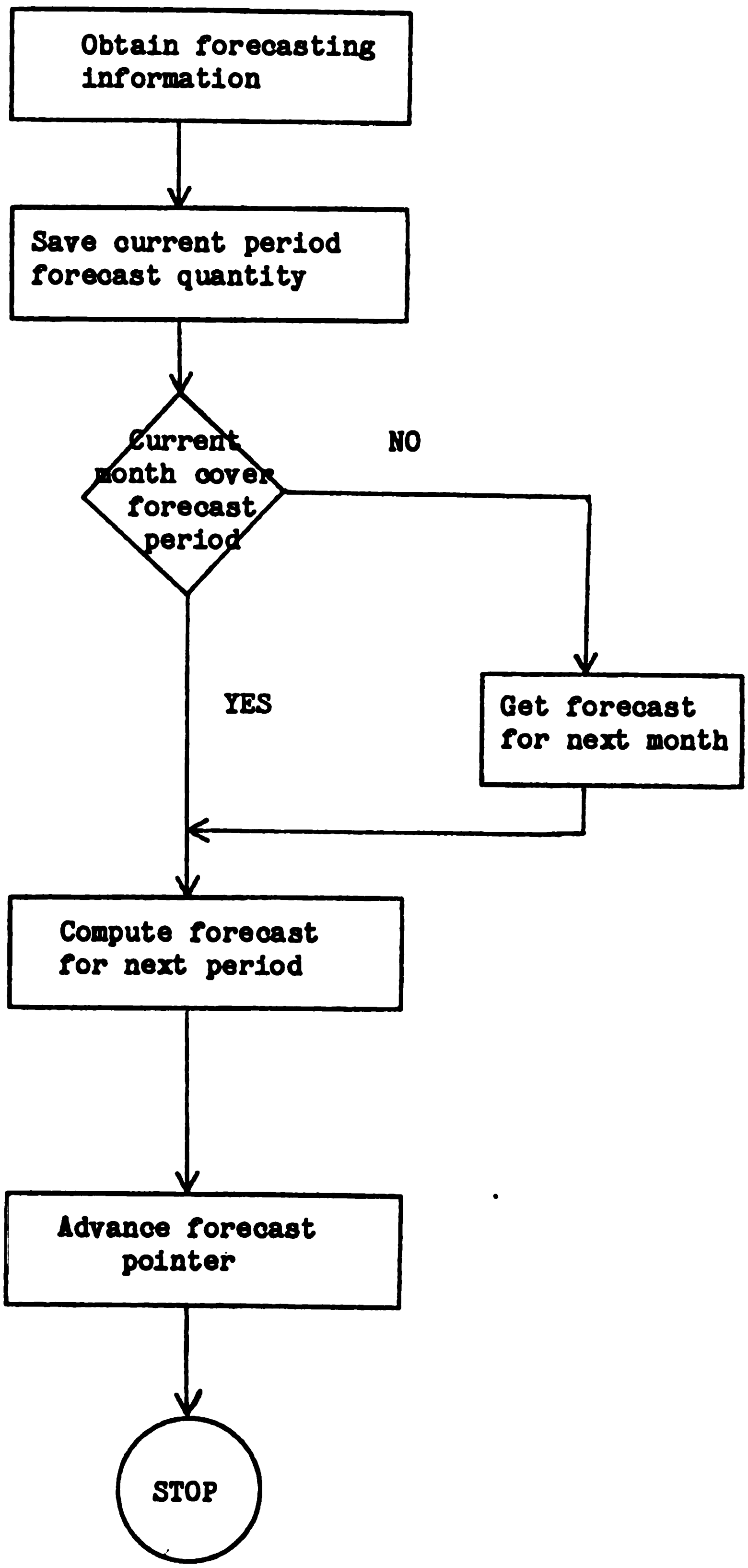


Figure A4: EVENT LOGIC FLOW - FORCTD

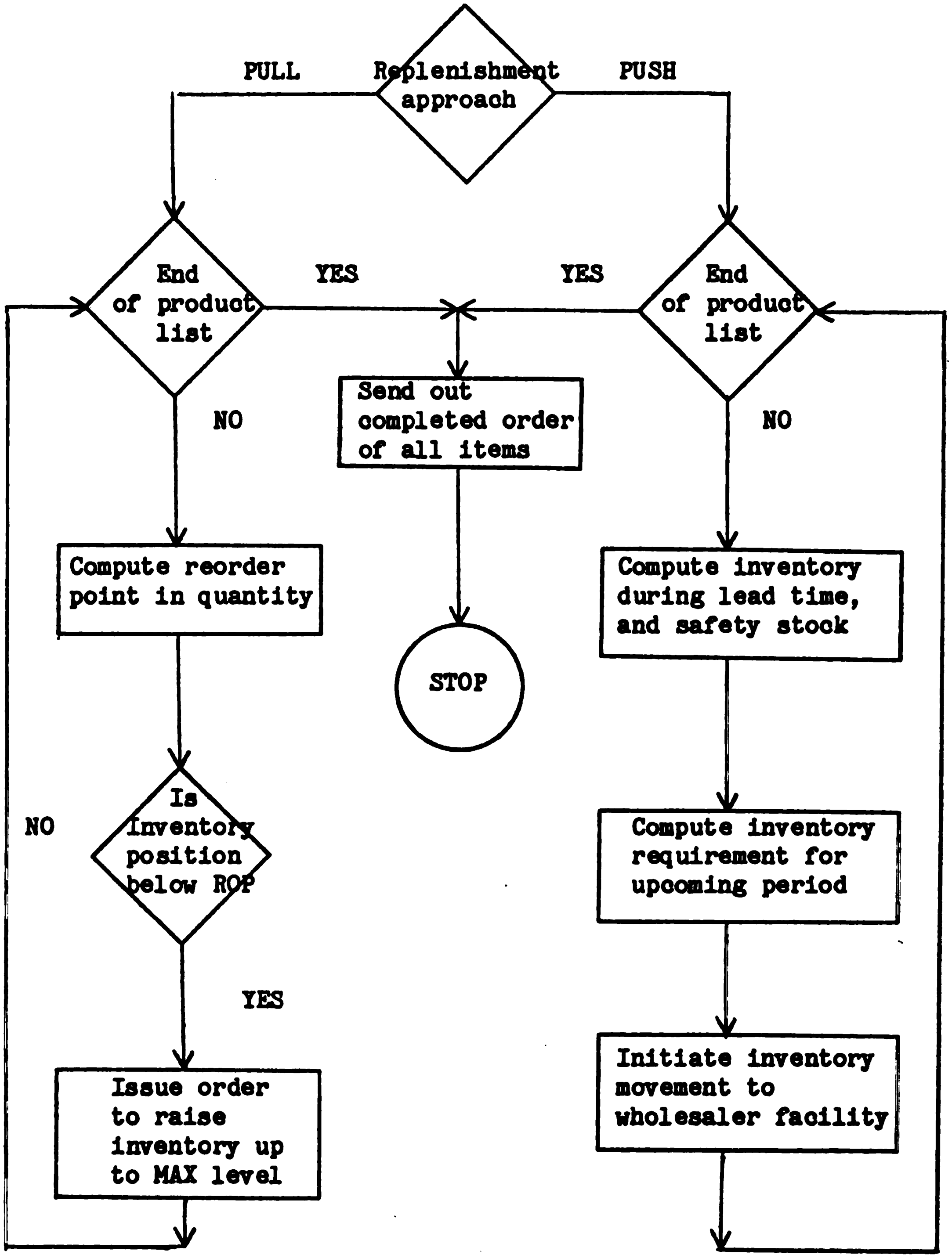


Figure A5: EVENT LOGIC FLOW - INVMGT

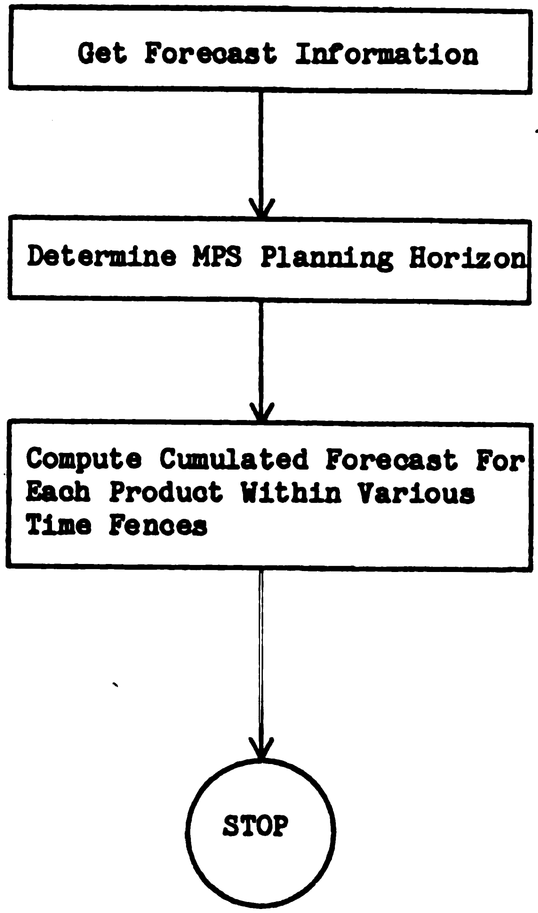


Figure A6: Event Logic Flow - FORCTP

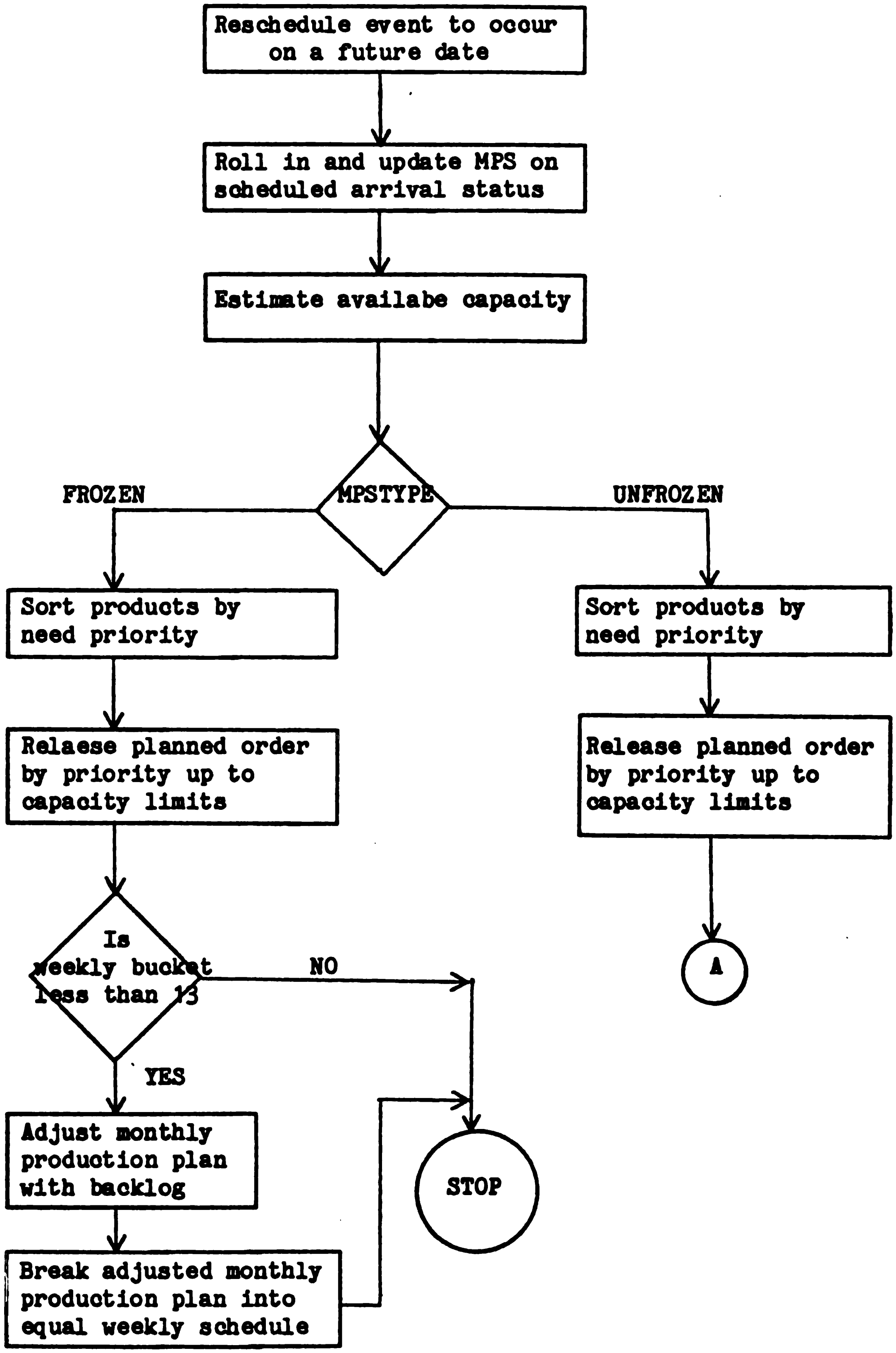


Figure A7: Event Logic Flow - PRDSCH

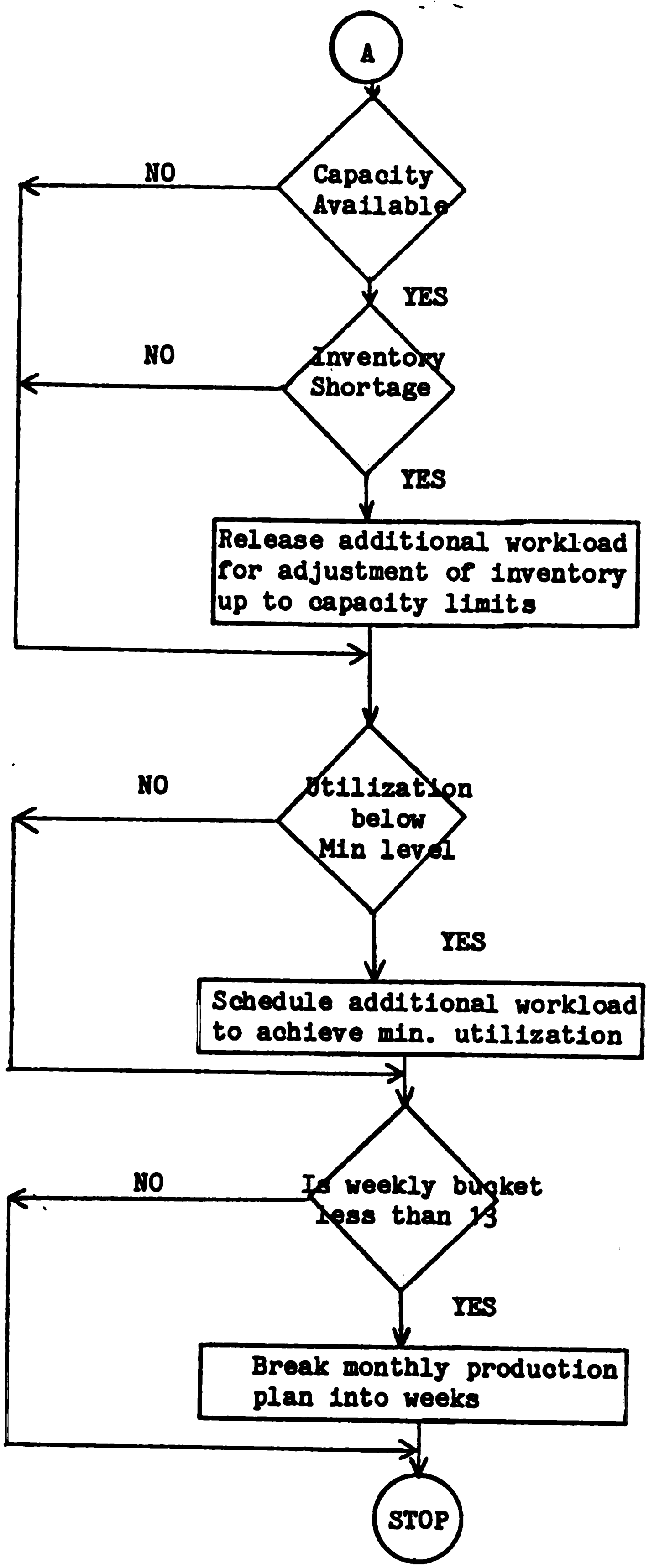


Figure A7: Event Logic Flow - PRDSCH(Continued)

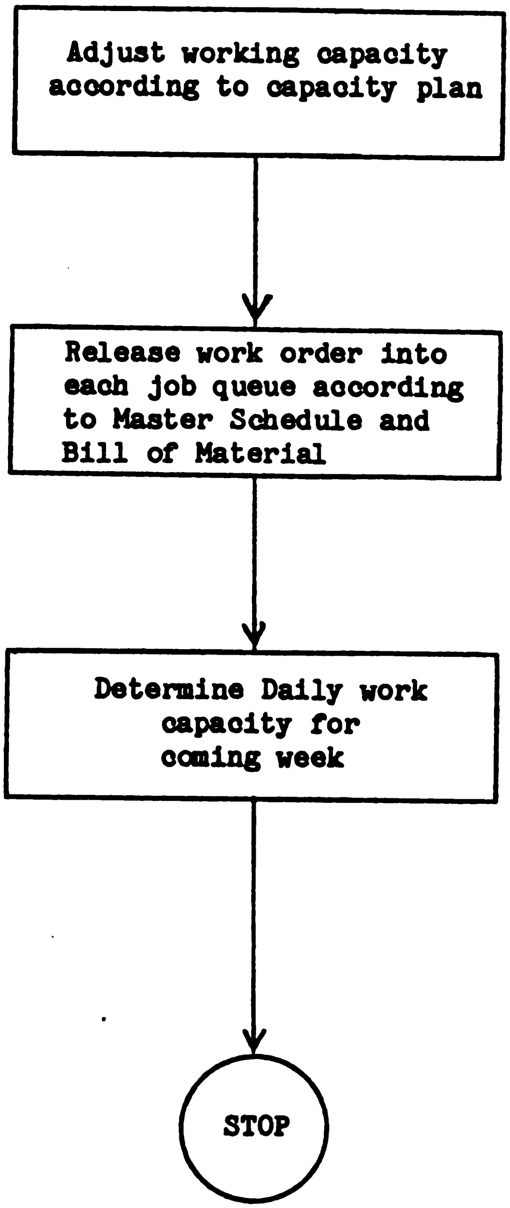


Figure A8: Event Logic Flow - PRODUC

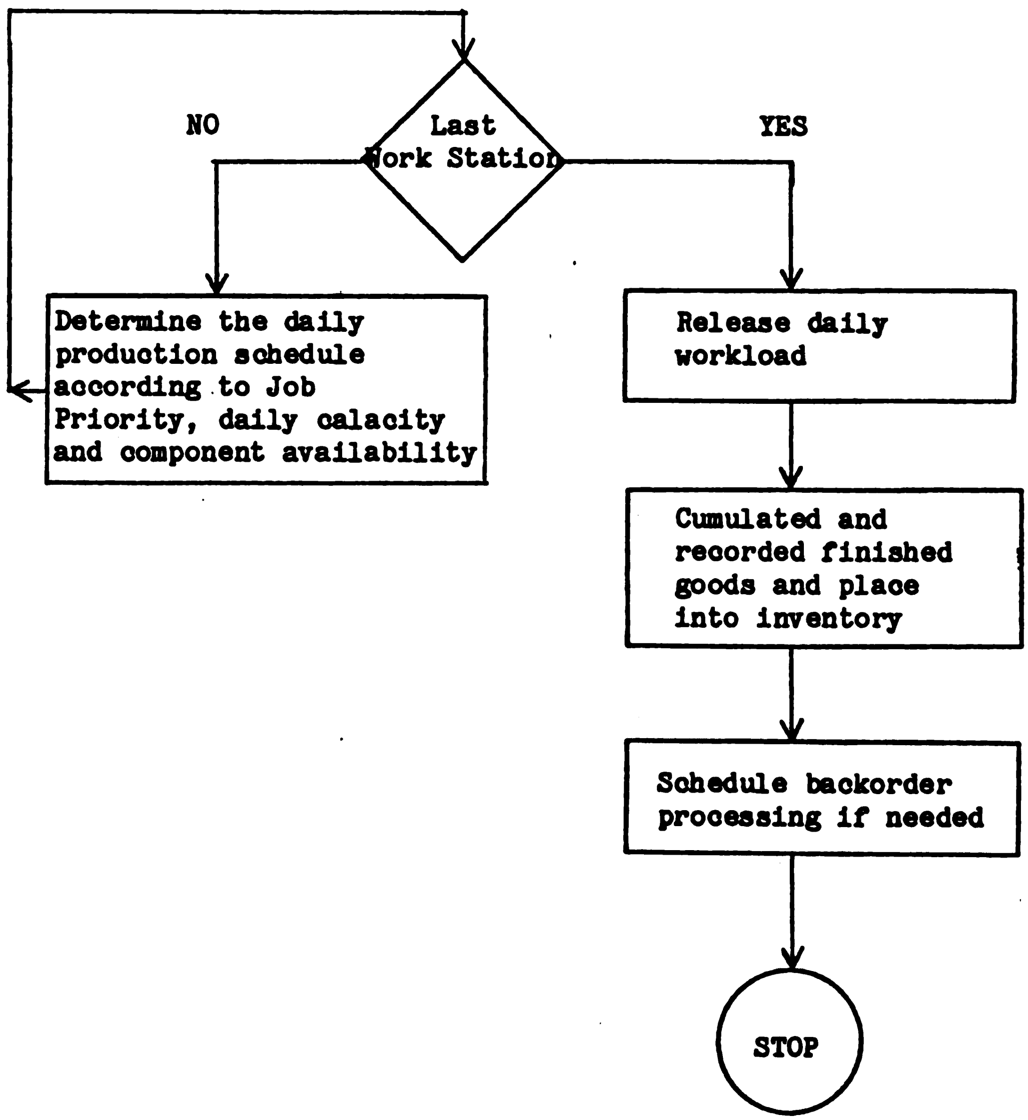


Figure A9: EVENT LOGIC FLOW - INVCUM

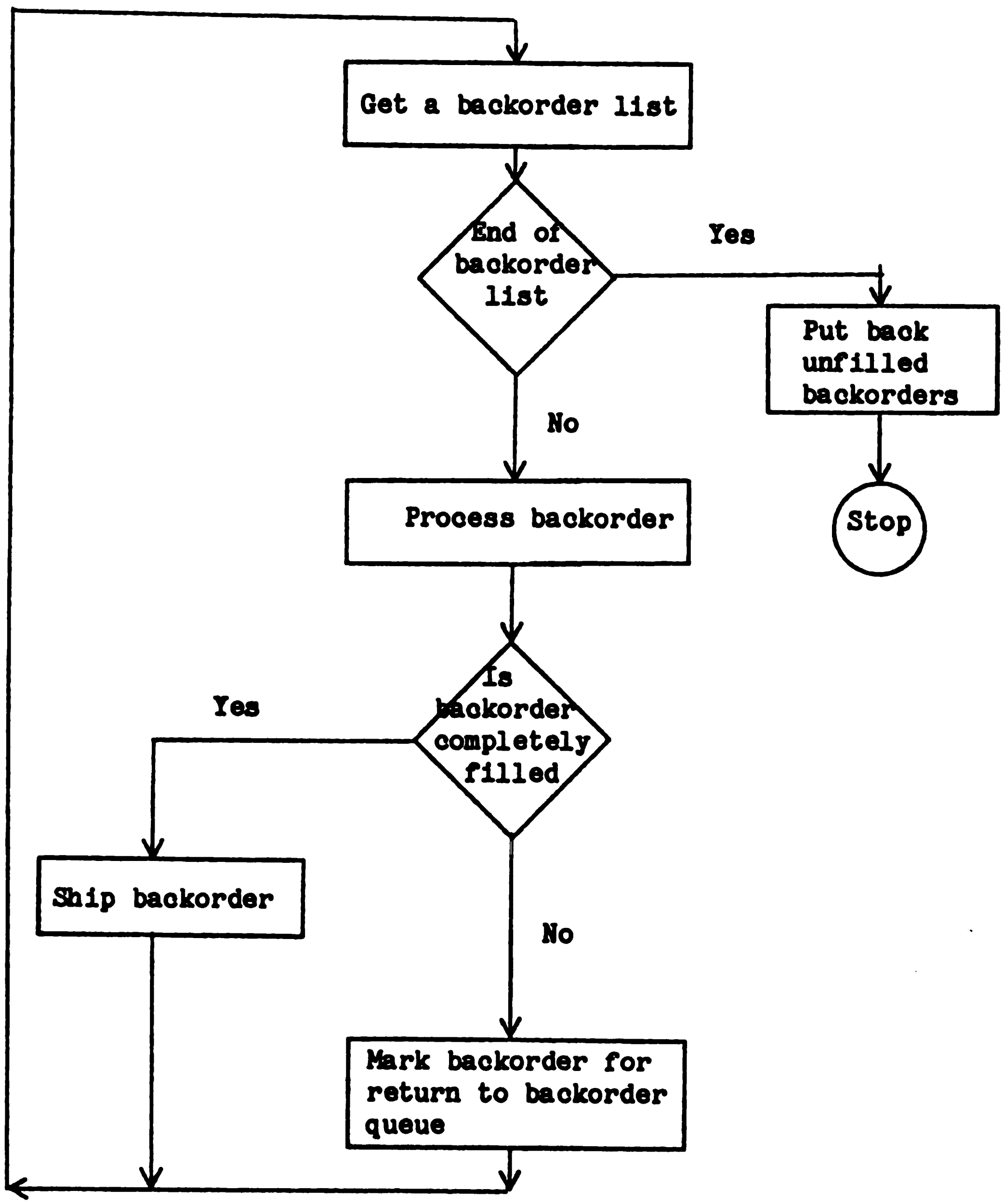


Figure A10: Event Logic Flow - BCKPRO

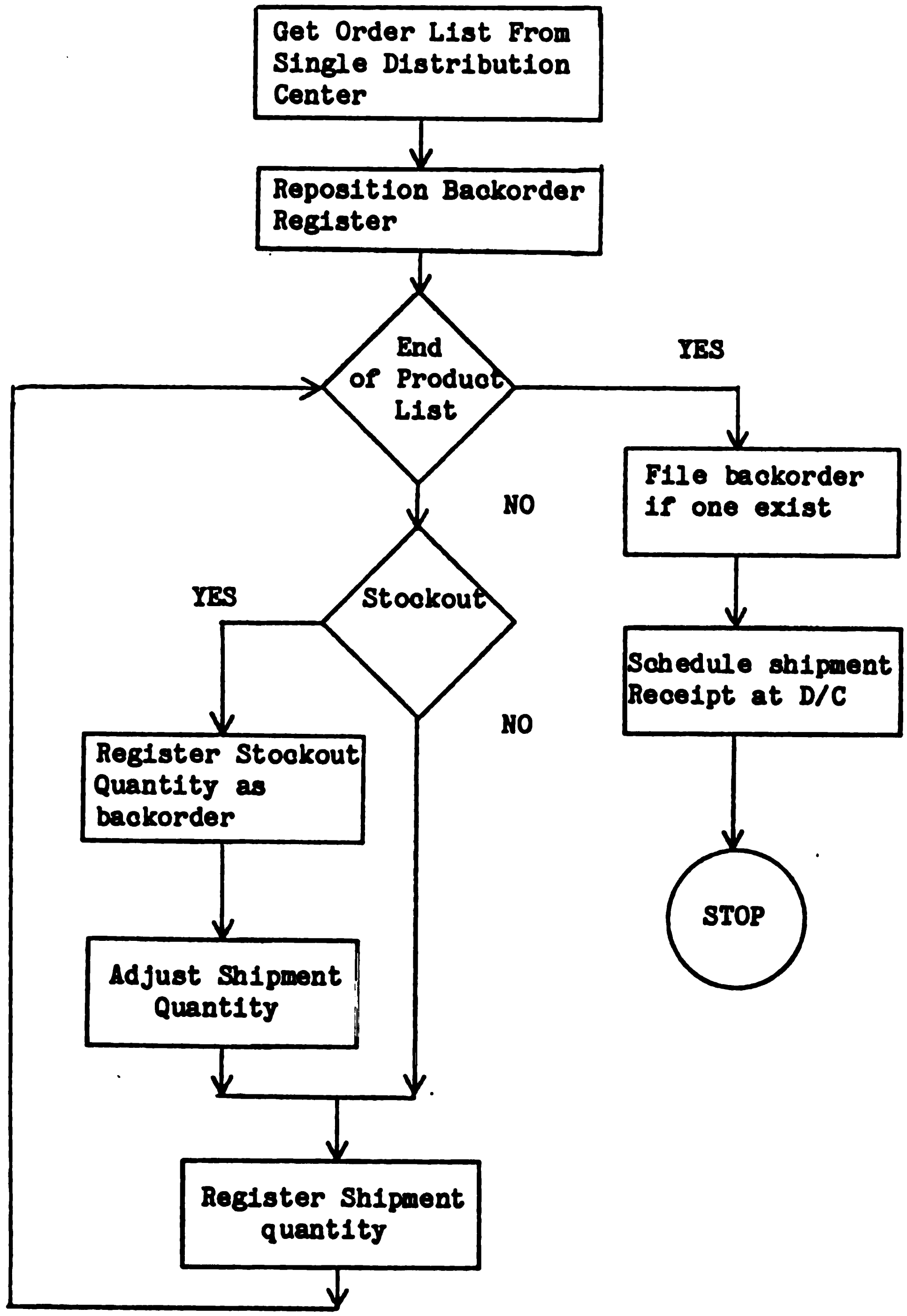


Figure A11: Event Logic Flow - ORDPR

APPENDIX B

Summary of Survey on Distribution System

The survey was sent to 40 top executives - vice presidents, or directors, of randomly selected distribution firms which are represented in the 1983 NCPDM national conference. The following are results from 10 surveys returned.

Production-Distribution System:	
Operate Production Facilities	8 firms
Operate Distribution Facilities	10 firms
Inventory Supply Source:	
Production Facility	9 firms
Outside Vendor	9 firms
Others	2 firms
Existence of Inventory Supply Problem:	
Yes	8 firms
No	1 firm
Adoption of master production schedule:	6 firms
Range of Planning horizon	4-52 weeks
Range of Firmed order period	2-18 weeks
Production lead time	2-12 weeks
Production Plan:	
Levelled production plan	2 firms
Variable production plan	2 firms
Stockout management at production level:	
Backordering	6 firms
Sales loss	2 firms
MPS adjustment:	4 firms

APPENDIX C

Initial Values for Selected Parameters

PARAMETERS	INITIAL VALUE
Plant Inventory Level	1 Week Supply
Job Queues	3 Weeks of Released Orders
DC Inventory Level	1 Week Supply
In-transit Inventory Level	None
Backorder Queue	Empty
Demand Season	Low Season
Statistics Counters	Clear
Production Targets	On Schedule for all items

Appendix D

Validation of Simulation Model

Table D4 : Validity of Simulated Distribution Patterns

Submodel	Theoretical Value		Simulated Value
Normal distribution generator CV = .11	mean	152.00	151.94
	SD	16.72	16.78
	mode	152.00	151.00
	mean	168.00	168.33
	SD	18.48	18.61
	mode	168.00	172.00
	mean	184.00	184.17
	SD	20.24	20.10
	mode	184.00	177.00
	mean	200.00	199.70
	SD	22.00	21.92
	mode	200.00	192.00
	mean	216.00	216.39
	SD	23.76	23.84
	mode	216.00	212.00
	mean	232.00	232.02
	SD	25.52	25.49
	mode	232.00	242.00
	mean	248.00	248.03
	SD	27.28	27.35
	mode	248.00	234.00

Table D4 (continued)

Submodel	Theoretical Value		Simulated Value
Normal distribution	mean	152.00	153.68
CV = .5	SD	76.00	74.96
	mean	168.00	169.95
	SD	84.00	81.89
	mean	184.00	181.05
	SD	92.00	90.95
	mean	200.00	201.55
	SD	100.00	97.45
	mean	216.00	216.47
	SD	108.00	105.13
	mean	232.00	232.80
	SD	116.00	115.92
	mean	248.00	248.26
	SD	124.00	120.66

Table D4 (continued)

Submodel	Theoretical Value		Simulated Value
Gamma Distribution Lead time CV = .14	mean SD mode	4.00 .56 4.00	4.02 .63 4.00
Gamma Distribution Lead time CV = .50	mean SD mode	4.00 2.00 3.00	4.00 2.00 3.00
Gamma Distribution Demand CV = .11	mean SD mode	152.00 16.72 150.16	150.79 16.61 154.00
	mean SD mode	168.00 18.48 165.97	166.44 18.32 160.00
	mean SD mode	184.00 20.24 181.77	181.99 20.19 178.00
	mean SD mode	200.00 22.00 197.58	198.72 21.64 201.00
	mean SD mode	216.00 23.76 213.38	214.56 23.48 204.00
	mean SD mode	232.00 25.52 229.19	230.00 25.81 234.00
	mean SD mode	248.00 27.28 244.99	245.56 27.39 243.00

Table D4 (continued)

Submodel	Theoretical Value		Simulated Value
Gamma Distribution Demand CV = .5	mean	152.00	151.35
	SD	76.00	76.64
	mode	114.00	107.00
	mean	168.00	165.96
	SD	84.00	84.34
	mode	126.00	113.00
	mean	184.00	184.82
	SD	92.00	92.67
	mode	138.00	156.00
	mean	200.00	200.29
	SD	100.00	98.72
	mode	150.00	167.00
	mean	216.00	217.00
	SD	108.00	105.33
	mode	162.00	174.00
	mean	232.00	230.67
	SD	116.00	115.00
	mode	174.00	130.00
	mean	248.00	249.81
	SD	124.00	128.35
	mode	186.00	152.00

COUNT	MIDPOINT
0	15.00
0	25.00
0	35.00
0	45.00
0	55.00
0	65.00
0	75.00
0	85.00
0	95.00
5	105.00
56	115.00
207	125.00
485	135.00
693	145.00
675	155.00
491	165.00
240	175.00
96	185.00
40	195.00
10	205.00
2	215.00
0	225.00
0	235.00
0	245.00
0	255.00
0	265.00
0	275.00
0	285.00
0	295.00
0	305.00
0	315.00
0	325.00
0	335.00
0	345.00
0	355.00
0	365.00
0	375.00
0	385.00
0	395.00
0	405.00
0	415.00
0	425.00
0	435.00
0	445.00
0	455.00
0	465.00
0	475.00
0	485.00
0	495.00
0	505.00
0	515.00
0	525.00
0	535.00
0	545.00

ONE SYMBOL EQUALS APPROXIMATELY 16.00 OCCURRENCES

0 160 320 480 640 800

HISTOGRAM FREQUENCY

c.v. = .11

MEAN 150.792 MEDIAN 150.000 MODE 154.000
STD DEV 16.609 SKEWNESS .294

COUNT	MIDPOINT
6	15.00
22	25.00
49	35.00
54	45.00
87	55.00
112	65.00
169	75.00
168	85.00
157	95.00
187	105.00
154	115.00
185	125.00
180	135.00
149	145.00
163	155.00
136	165.00
107	175.00
111	185.00
112	195.00
80	205.00
88	215.00
80	225.00
69	235.00
56	245.00
42	255.00
40	265.00
43	275.00
29	285.00
27	295.00
17	305.00
17	315.00
23	325.00
10	335.00
11	345.00
7	355.00
12	365.00
5	375.00
9	385.00
4	395.00
2	405.00
3	415.00
5	425.00
2	435.00
5	445.00
2	455.00
1	465.00
1	475.00
1	485.00
0	495.00
0	505.00
0	515.00
0	525.00
0	535.00
0	545.00

ONE SYMBOL EQUALS APPROXIMATELY 8.00 OCCURRENCES

0 80 160 240 320 400

HISTOGRAM FREQUENCY

c.v. = .50

MEAN 151.349 MEDIAN 138.000 MODE 107.000
STD DEV 76.638 SKEWNESS .998

Figure D1 Generated Gamma Demand Patterns

COUNT MIDPOINT ONE SYMBOL EQUALS APPROXIMATELY 30.00 OCCURRENCES

COUNT	MIDPOINT
0	5.00
0	15.00
0	25.00
0	35.00
0	45.00
0	55.00
0	65.00
0	75.00
0	85.00
1	95.00
19	105.00
116	115.00
315	125.00
695	135.00
1035	145.00
1219	155.00
832	165.00
490	175.00
206	185.00
48	195.00
9	205.00
1	215.00
0	225.00
0	235.00
0	245.00
0	255.00
0	265.00
0	275.00
0	285.00
0	295.00
0	305.00
0	315.00
0	325.00
0	335.00
0	345.00
0	355.00
0	365.00
0	375.00
0	385.00
0	395.00
0	405.00
0	415.00
0	425.00
0	435.00
0	445.00
0	455.00
0	465.00
0	475.00
0	485.00
0	495.00
0	505.00
0	515.00
0	525.00
0	535.00

0 300 600 900 1200 1500
HISTOGRAM FREQUENCY

c.v. = .11

MEAN	151.939	MEDIAN	152.000	MODE	151.000
STD DEV	16.780	SKEWNESS	.033		

COUNT MIDPOINT ONE SYMBOL EQUALS APPROXIMATELY 16.00 OCCURRENCES

COUNT	MIDPOINT
137	5.00
57	15.00
64	25.00
78	35.00
105	45.00
103	55.00
158	65.00
164	75.00
177	85.00
205	95.00
205	105.00
201	115.00
231	125.00
274	135.00
239	145.00
272	155.00
243	165.00
275	175.00
219	185.00
217	195.00
203	205.00
181	215.00
175	225.00
171	235.00
110	245.00
109	255.00
107	265.00
77	275.00
62	285.00
40	295.00
42	305.00
32	315.00
22	325.00
16	335.00
8	345.00
6	355.00
6	365.00
5	375.00
0	385.00
1	395.00
3	405.00
0	415.00
0	425.00
0	435.00
0	445.00
0	455.00
0	465.00
0	475.00
0	485.00
0	495.00
0	505.00
0	515.00
0	525.00
0	535.00

0 160 320 480 640 800
HISTOGRAM FREQUENCY

c.v. = .5

MEAN	153.681	MEDIAN	153.000	MODE	0
STD DEV	74.961	SKEWNESS	.113		

Figure D2 Generated Normal Demand Patterns

APPENDIX E

Parameter Sensitivity Analysis (selected cases)

Case 1: Pull Inventroy Approach and Unfrozen MPS

Parameter	Initial Value	Averag Inventory level	Average Service level
Wholesaler	1800	3457	.991
Onhand	2500	3455	.992
Inventory	3000	3454	.993
Plant Finished	2544	3455	.992
Goods Inventory	3180	3455	.992
	4452	3455	.992
Plant WIP	36000	3506	.955
Inventory	54000	3455	.992

Case 13: Push Inventory Approach and Frozen MPS

Parameter	Initial Value	Averag Inventory level	Average Service level
Wholesaler	1800	2782	.993
Performance	2500	2784	.995
Plant Finished	2544	2783	.993
Goods Inventory	3180	2784	.995
	4452	2790	.987
Plant WIP	36000	2788	.971
Inventory	54000	2762	.996
(component A, D)			

APPENDIX F

Steady State Analysis

The following tables summarize selected results on T-test for equality of population means over time. Three semi-annual averages being analyzed are: average distribution inventory position (INV), average quantity fill rate (SVC) and average plant inventory (PINV). Repeating T-test for different initial conditions indicates the system enters steady state at year 3. (Critical T value with D.F. = 102 at .01 confidence level equals 2.62)

<u>Inventory</u>:

Case 4 - Initial Plant Inventory = 1 week supply

Sampling Time	Mean	Standard Deviation	Pooled T Value	Variance D.F.	Estimate 2-Tail Prob
year 2	3802	839.7	.33	102	.741
year 3	3748	840.9			
year 3	3748	840.9	.05	102	.964
year 4	3740	815.0			

Case 4 - Initial Plant Inventory = 2 weeks supply

Sampling Time	Mean	Standard Deviation	Pooled T Value	Variance D.F.	Estimate 2-Tail Prob
year 2	3787	779.8	.25	102	.803
year 3	3748	840.9			
year 3	3748	840.9	.05	102	.964
year 4	3740	815.0			

Appendix F (cont'd)

Services:

Case 4 - Initial Plant Inventory = 1 week supply

Sampling Time	Mean	Standard Deviation	Pooled T Value	Variance D.F.	Estimate 2-Tail Prob
year 2	.961	.128	-1.96	102	.053
year 3	.996	.020			
year 3	.996	.020	1.36	102	.178
year 4	.976	.103			

Case 4 - Initial Plant Inventory = 2 weeks supply

Sampling Time	Mean	Standard Deviation	Pooled T Value	Variance D.F.	Estimate 2-Tail Prob
year 2	.977	.079	-1.69	102	.094
year 3	.996	.020			
year 3	.996	.020	1.36	102	.178
year 4	.976	.103			

Appendix F (cont'd)

Plant Inventory:

Case 4 - Initial Plant Inventory = 1 week supply

Sampling Time	Mean	Standard Deviation	Pooled T Value	Variance D.F.	Estimate 2-Tail Prob
year 2	2792	1641	-10.49	102	0
year 3	9591	4378			
year 3	9591	4378	-1.67	102	.10
year 4	10693	1873			

Case 4 - Initial Plant Inventory = 2 weeks supply

Sampling Time	Mean	Standard Deviation	Pooled T Value	Variance D.F.	Estimate 2-Tail Prob
year 2	3930	2074	-10.72	102	0
year 3	11700	4799			
year 3	11700	4799	-2.50	102	.014
year 4	13513	2092			

Appendix F (cont'd)

Case 25:

<u>Inventory</u>:

Sampling Time	Mean	Standard Deviation	Pooled T Value	Variance D.F.	Estimate 2-Tail Prob
year 2	2416	427	.23	102	.819
year 3	2397	432			
year 3	2397	432	-.08	102	.934
year 4	2404	418			
year 4	2404	418	.05	102	.963
year 5	2400	431			

<u>Service</u>:

Sampling Time	Mean	Standard Deviation	Pooled T Value	Variance D.F.	Estimate 2-Tail Prob
year 2	.985	.068	-.87	102	.384
year 3	.994	.029			
year 3	.994	.029	-1.45	102	.151
year 4	1.000	0			
year 4	1.000	0	-1.09	102	.279
year 5	.997	.022			

Appendix F (cont'd)

Case 25

<u>Plant Inventory</u>:

Sampling Time	Mean	Standard Deviation	Pooled T Value	Variance D.F.	Estimate 2-Tail Prob
year 2 year 3	3625 4122	2150 1790	-1.28	102	.203
year 3 year 4	4122 4149	1790 1964	-0.07	102	.943
year 4 year 5	4149 3908	1964 1773	0.66	102	.512

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