The Influence of Just-in-Time Systems on Physical Distribution Channel Performance: An Experiment Utilizing A Dynamic Simulation Decision Support System

by

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(ABSTRACT)

Currently many American industrial firms are considering the adoption of Just-In-Time (JIT) as an inventory control/material flow system. A JIT system can have several configurations. Examples exist of JIT being applied system-wide between all the echelons which make up a channel. There are also examples of firms adopting JIT only on the materials management side, or alternatively, only on the physical distribution side of a particular focal organization (echelon) within a channel.

The reality of uncertainty in the channel's operation and environment suggests that alternative inventory systems (such as JIT) must be evaluated under a range of internal operational uncertainty and external demand uncertainty conditions. This study offers a rational methodology to anticipate the performance impact of alternative system designs under realistic operating conditions.

The G.P.M. simulation model was used to represent the operation of a channel under sixteen treatment conditions. The research design was full factorial with two levels each of four factors (physical distribution

JIT, materials management JIT, materials management operational uncertainty, and demand uncertainty). The response variables which were used as indicators of channel performance included: profitability, order cycle time, standard deviation of order cycle time, and percent customer orders filled.

Eleven research hypotheses explored the relationship between JIT configuration and uncertainty, both in terms of profitability and physical distribution service level maintained.

The major conclusions of the research are:

1. JIT is not the unidimensional system often depicted in descriptive studies. JIT effects tend to be complex, interactive, and level dependent. It is particularly difficult to predict the effect of JIT on one echelon, or on subsystems within echelons.

2. Rather than the inherent positive effects often attributed to JIT, results indicate negative effects for both profit and service under a range of uncertainty conditions.

3. Results support the common criticism of JIT that its performance is sensitive to uncertainty, particularly demand uncertainty. The performance of non-JIT systems were also shown to have similar sensitivity to uncertainty.

4. Most synergistic interactions between factors were not significant, but the statistical procedure for means comparison was acknowledged to be conservative.

5. Results also indicated that JIT systems may make the job of maintaining high customer service levels more difficult.

DEDICATION

This research effort is dedicated to my wife and to my daughter . This study could not have been completed without their support and sacrifices across the last four years.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

INTRODUCTION TO JUST-IN-TIME

In the mid-1960's, United States manufacturers dominated the production of a wide range of products (e.g., steel, textiles, automobiles, shoes, electronics, machine tools, heavy equipment, etc.). Since that time, the growing technological capabilities of foreign competitors and the availability of economical and reliable modes of transportation have allowed foreign producers to take over many of these markets. Those American companies remaining in competition are struggling to adapt to a market place where efficiency and performance are increasingly important. In such a competitive situation, the advantage goes to the supplier of goods or services which is perceived by the market to be providing the best value (i.e., best quality, most satisfaction, most utility, for the price required). This advantage (usually in market share) occurs whether the market is made up of final consumers or industrial customers. The supplier losing market share will often look to forces outside of the firm as causal, rather than looking within to its own policies and operations. This seems to be particularly the case for American industry as they have lost share in market after market to foreign producers.

The introduction of foreign owned manufacturing operations in the United States has shown that not all of the blame for America's problems can be placed on outside forces such as high domestic wage rates, lack of domestic work ethic, and foreign government subsidization of manufacturing. It is beginning to be recognized by some firms that a major part of the foreign advantage has been due to better systems and methods of production (e.g., better inventory control, supplier relations, quality control). As American producers become aware of better systems and methods, they have investigated their potential for application in their own operations and in many cases have adapted or adopted them for their own use (Raia 1986). A great deal of interest and effort has been expended on the adoption of the Japanese production system commonly referred to as Just-in-Time or Kanban.

The most common notion of Just-in-Time (JIT) usually relates to its reduction of inventory all along the logistics system (raw material inventory, in process inventory, and finished goods inventory). JIT is actually more than this. It is an integrated philosophy of operating a business which typically features centralized purchasing, sole source suppliers, long term contracts, and small-lot inventory-less production with materials delivered just as needed. In order to adopt JIT, a typical American firm would have to be willing to make major changes in manufacturing, purchasing, marketing, transportation, customer service, and selling. Although the impact of JIT would be likely to vary greatly from firm to firm, Haley and Piper (1986) suggest typical improvements may include:

1. reduction in raw material inventories (and supplier inventories).
2. work-in-process inventory reductions.
3. storage space reductions.
4. reduced production of defect products.
5. reduced lead times.
6. reduced obsolescence costs.
7. reduced materials handling costs.
8. reduction in machine set up times.
9. a much reduced supplier base due to sole sourcing.
10. significant volume discounts due to increased volume with sole source suppliers and resulting increase of negotiating power of the customer.

This is part of what makes JIT different and special. Any system which can provide such benefits at a time that finds American industry in decline is important and worthy of study. It is particularly worthy of study by marketing researchers because it impacts logistics, customer relations, buyer behavior and pricing. It is also important to remember that the decision to implement JIT (and in what form to implement it) is often a strategic planning decision made wholly or in part by marketing. While the concept of a JIT system will be described in detail in Chapter II, it is enough at this point to consider Just-in-Time as a system which is different from the systems used by most U.S. industries and that many of these differences occur in the operation of logistics systems (i.e., material procurement, holding, and movement).

DEFINITIONS

To consider the issues involved in JIT it is useful to define the terms which are basic to logistics research. The adoption of JIT suggests changes in the manner in which firms will deal with one another (e.g., goods arriving just in time for use, integration of supplier and customer goals). Thus, JIT impacts relations all along the channel of distribution.

A channel of distribution is defined as the set of all firms that cooperate to produce, distribute and consume the particular good or service of a particular producer (Rosenbloom 1978). The logistics material flow system of a particular firm (focal organization) within this channel can be simply represented by:

```
                input                            output
Supplier ----------> Focal Organization ----------> Demand
```

The input refers to raw material acquisition, incoming transportation, and raw material storage. Within the focal organization the material flow concerns materials handling, in-process inventory and finished goods storage. The term which is used to refer to these activities which involve material flow in and through the focal organization is materials management. The output flow is referred to as physical distribution and deals with all of the activities required to physically move the product from the firm to its demand points. Thus, a firm's material flow can be represented by:

```
 Materials               Focal                    Physical
--------------->----------------------->------------------
 Management              Organization             Distribution
 System                                           System
```

From this description it can be seen that the physical distribution system of a supplier is also part of the materials management systems of its customer firms. Thus, the study of physical distribution is closely related to many aspects of the study of materials management.

STATEMENT OF THE PROBLEM

To illustrate the problem of JIT adoption, consider an example of a simplified automobile industry channel as follows:

----> Supplier ----> Manufacturer ----> Dealer ----> Demand

The total adoption of JIT throughout the channel would imply goods arriving just as needed between dealer and manufacturer, manufacturer and supplier, and supplier and its sub-suppliers back up the channel. If this was the only approach to JIT implementation, research would be greatly simplified. The current state of JIT implementation in American industry often falls short of this total "system-wide" approach. It is common for a manufacturer (e.g., automobile, appliance) to put JIT in place with its suppliers (i.e., in its materials management system) while continuing non-JIT practices with its dealer's (i.e., in its physical distribution system). The manufacturer's supplier now has JIT in its physical distribution system possibly without JIT in its materials management system. This implies four configuration options for firms considering JIT.

1. Materials management JIT only
2. Physical distribution JIT only
3. Both materials management and physical distribution JIT
4. Non-JIT (conventional materials management and physical distribution)

In light of the various JIT configurations described above, it is clear that firms must have some rational methodology to anticipate the performance impact of these alternatives before they choose among them. Currently many firms are considering adopting some form of JIT and examples exist of implementation in all three configurations.

While some empirical JIT studies have been done from a management science perspective, the topic has not yet attracted significant empirical marketing research attention. Thus, what little is known about the impact of JIT systems is in terms of management science operational issues rather than marketing's distribution service measures.

It will be shown in Chapter II that all JIT research can be placed in a 2 x 2 typology according to research approach (conceptual, empirical) and level of analysis (non-system, total system) (Gomes and Mentzer 1988). Placing available studies within this map will show that a significant research gap exists in the empirical/total system quadrant.

Objectives of Research

The objectives of this research are to empirically explore the performance of JIT alternative configurations from a total system perspective. Buckley (1972) stated that "adequate epistemological (as well as ontological) analysis must focus on the total system as a complex on-going whole, for the information selection, transformations, or codings that occur at any point or linkage in the system depend not only on prior events and processes in the system, but also on feedbacks from later points."

This recognition of the necessity of a total system, feedback, temporal approach suggests the conceptual frame work and methodology of the proposed research (General System Theory/ dynamic simulation).

Conceptual Framework

The importance of the total system approach to such research cannot be overstated. Previous studies which have considered JIT subsystems in isolation have made the tacit assumption that such subsystems could be considered closed systems (not interactive). Using inventory models as an example, Churchman (1979) cautioned against ignoring such interactions in stating that "all so-called subsystems, like inventory or service units, are really not "sub" at all and are strongly nonseparable from the whole system."

The conceptual framework of this research can be found in General Systems Theory (GST). The concept of GST will be introduced here but much will be left for the literature review of Chapter II.

Briefly, traditional science studies phenomena by reduction to the interplay of elementary units which can be investigated in isolation (the Newtonian science approach). The GST paradigm offers a general science of wholes, and is concerned with the interrelation of parts and, when considering open systems, interactions with the environment (Reason 1980). Further, GST concerns itself with the formulation and derivation of principles that are applicable to systems in general, irrespective of whether they are of physical, biological or sociological nature (von Bertalanffy 1968).

Thus, GST principles (which should apply to systems in general) may be used to provide the conceptual framework for studing the propositions of JIT in a marketing environment.

Statement of Research Questions

Use of the GST paradigm implies fundamental views of the nature of things in accordance with what is usually referred to as principles of systems thinking (Klir 1978). One of the important fundamental views in systems thinking is the principle of wholeness: "the whole is more than the collection of its parts" (Klir 1978). Applying this systems view to alternative JIT configurations suggests that system-wide (bothsides) JIT should outperform (in profit) the application of JIT to just one side of the firm's material flow. Also, there should be a positive interaction between materials management JIT and physical distribution JIT. These suggestions can be stated as research questions to be later investigated by statistical hypothesis testing.

With a similar approach the following general research questions will also be explored:

1. Do all JIT configurations have a positive impact on profit performance?
2. Which JIT configuration results in the highest profit performance?
3. How are the results of 1. and 2. above impacted by the presence of uncertainty of physical supply (materials management uncertainty) and/or uncertainty in demand?
4. What are the results of 1., 2. and 3. above when physical distribution service is used as the response variable?

Research Methodology

Research in the GST paradigm not only dictates systems thinking, it also requires methodology appropriate to systems investigation. Orchard (1972) stated that it appears computer simulation will play an increasingly important role in carrying out general system theoretic studies and the necessary systems modeling involved. Beer (1980) similarly observed that systems thinking can be applied to model building, as in the case of computerized simulation models.

Therefore, the research methodology proposed will utilize a computer simulation of the supplier-producer-demand channel upon which various JIT configurations can be imposed in the presence of various materials management and demand uncertainty.

Theoretically, it would be possible to conduct the research experiment on an actual channel but this was rejected based on: 1. firms would be unwilling to participate due to negative treatments, 2. the time and cost of manipulations would be prohibitive, and 3. the lack of control of confounding factors in real world operations.

One practical research instrument seems to be a computer simulation model with the capability of representing the channel operation with sufficient detail and sensitivity. The operation of such a model will be outlined in Chapter III.

SIGNIFICANCE AND POTENTIAL CONTRIBUTION

It is well established that Just-in-Time (Kanban) systems are being applied in different configurations to industries which operate under different environmental constraints (Jackson and Morgan 1983). While some recent research has investigated physical distribution service level (a measure of distribution system performance) in conventional systems, none have expanded this to Japanese type systems as applied to U.S. operations. This study, therefore, has considerable potential to add to the understanding of JIT/PDS relationships and to provide insights for managerial decision makers and distribution researchers.

It does not seem likely that Just-in-Time (Kanban) systems can be applied haphazardly in any form, to any company, in any situation. This suggestion is similar to one developed by Jerman and Anderson (1976) who applied the "contingency approach" to physical distribution decision making. They stated that, "the contingency approach has a philosophy of relativism," that is, "management concepts and tools are not universally applicable but are only appropriate if the right conditions exist in a given situation." This is as opposed to the "process approach" to theory application which involves absolute principles and universal applications.

To utilize the "contingency approach" a manager must not only have a complete situational analysis but also have access to current beliefs concerning critical variable relationships. This research is an attempt to provide some understanding (beliefs) of JIT, how it works, when it should be applied, and how it will likely be affected by uncertainty. Managers (often strategic marketing planners) must make decisions concerning distribution system configuration. Research such as the study proposed here can help to assure that JIT concepts are only applied in appropriate situations.

Very possibly, JIT systems (correctly applied) will soon be required of all world class producers operating in competitive markets. Thus, this study should prove timely and produce guidelines for the organizational situations were JIT can best be applied (for operations similar in configuration and environmental situation to the model studied). These results should be of interest to both researchers and logistics managers.

POTENTIAL CONTRIBUTIONS TO LOGISTICS PRACTICE

It is expected that the current highly competitive global business environment will continue to force American industry to consider closer channel integration and cooperation. In this environment, logistics managers will be making critical strategic policy decisions concerning logistics system configuration and operation.

While the manipulation of marketing mix variables allows the logistics manager to set policy and affect factors such as the distribution, mean, and temporal characteristics of demand, existing theory provides little guidance for these managers when JIT is involved. It can be intuitively expected that JIT configuration (a proposed independent variable) will impact profit and physical distribution service levels (proposed dependent variables) differently under varying levels of uncertainty in materials management operation and demand (also proposed independent variables). This research is intended to provide measures of the nature and magnitude of these relationships. Given the costs and competitive risks associated with these decisions, investigations such as the one proposed are an important source of managerially useful data and understanding.

Other managerially useful results of the study will be guidelines concerning the performance and service trade-offs to be expected under different configurations of JIT application. Of particular interest will be results with JIT applied only on the physical distribution side. This is the position in which many suppliers find themselves when large customers adopt JIT on their materials management side. A major contribution of this study will be as the first published analysis of JIT applied to the physical distribution side of an operation. Previous studies have tended to consider only materials management and production aspects of JIT.

Examples of questions these managerial guidelines will address are:

> How superior is total system-wide JIT versus JIT only on the materials management or only on the physical distribution side?
>
> How sensitive is this to the nature of the organization's environmental conditions of materials management operational and demand uncertainty?
>
> How useful is computer simulation of logistics systems for evaluating alternative configurations of JIT in organizations?

It is expected that the application of JIT will not be found to be appropriate in all situations. This study will provide guidelines on how the adoption process should proceed and what performance results can be expected.

POTENTIAL CONTRIBUTIONS TO LOGISTICS THEORY

Managerial guidelines for performance and service trade-offs can be provided by researchers who advance the current understanding of JIT and thus add to existing logistics theory. Information on the interrelationships of JIT with cost, profit, service and uncertainty would be major theory contributions. The literature review in Chapter II will indicate a lack of an empirically tested theory of these relationships from a total system perspective. In fact, not even a specific conceptual relationship has been suggested.

Recent advances in computer capacity and operation now allow the simulation of complex logistics systems at reasonable costs in terms of time and resources. With more computational power available, researchers can more rigorously represent the operation of logistics systems and thereby increase the scope, power and detail of their controlled experiments. The proposed research will utilize a newly available complex system model which is unique and realistic enough that its performance in this application will advance the existing knowledge of simulation and decision support system applications in logistics.

The newly available research tool (the Global Planning Model) will be used to contribute to the currently limited theory and understanding of the interdependence and interaction of JIT (Kanban) systems with the critical dimensions of physical distribution service and total profit performance. The importance of these interactions will be discussed in detail and it will be shown that previous research has not investigated this area. Thus, the final important contribution of this study will be as the first investigation of interactions among, (1) types of distribution systems and (2) types of uncertainty, studied from the total systems perspective suggested by General System Theory (GST). The significance of this will be explored in a later section which covers GST and the necessity of its application to logistics research such as this study which investigates JIT.

POTENTIAL LIMITATIONS OF THE RESEARCH

All research is characterized by inherent limitations and potential problems. A design weak in one area may be robust in another. It is important for the researcher to advise the reader of such limitations to prevent misunderstanding, misgeneralization and misuse of the results.

Limitations and problems with this type of simulation model may include:

(1) Generalization - Computer simulation studies are often conducted with a model configured to represent a single firm or at best a limited number of firms. It must be noted that a model response typical of the average firm may not be close to the actual response of any single firm. To generalize from the results a random sample from all possible model (firm) configurations would have to be taken. To create a functional model of a single firm is a significant undertaking. To represent many possible types of firms would not be practical, so generalizability of results is limited.

(2) Model validity - Although a validation procedure is used, the question of how accurately the system can replicate the real world under various conditions and times is always a question. If actual company historical performance and operating data are supplied to a model, it is possible to show that the model's response is not significantly different (at some preset alpha level of significance) from the company's actual historical response. Although this is an important test to establish the credibility of the model, agreement over this limited range of actual historical results does not necessarily imply that the model will respond as the company would over all possible conditions. This is particularly of concern when investigating the upper and lower limits of relationships. Results should therefore only be considered relevant to relationships within the range of test conditions investigated.

(3) Statistical appropriateness - Without insight into computer simulation theory it is not clear that the factors measured met the statistical requirements of true independence, normal distribution, and equal variance. The most critical assumption is that the samples are independent (drawn from different populations) and that the observations in one sample are not a function of observations in another sample. If this assumption is not met the power of the F-test is reduced and it may provide erroneous results. Similarly, observations from populations which are not normally distributed with equal variance are also a violation of the assumptions of the F-test. Unless these concerns can be satisfied nonparametric tests should be considered. Since

observations in computer simulation are often few in number (central limit theorem may not apply) and are drawn from the same mathematical model (a possible indication of a functionally dependent time series) satisfying these assumptions can be a problem.

(4) False confidence - Computer simulations are often complex and can produce vast realistic looking quantitative results. Successful results on initial runs can sometimes promote false confidence that the model can properly represent any variation over any period of time. Firms using simulations to compare alternative strategies will usually only implement one strategy. While the results of this strategy will be known, the accuracy of the model's predictions for the alternative strategies will always be unknown. Because of this it is difficult to assess the model's capability limits. Users should have knowledge of the model's assumptions and function to avoid false confidence in a "black box" that is always appropriate and capable.

Even with these limitations and problems, simulation modeling has developed into a powerful tool to study complex relationships. Justification for its use in this study will be discussed next in terms of the above limitations.

Addressing problems (1) - (4) above:

(1) Although the ability to generalize is limited, the model used does represent the general form of a type of organization which is common in the marketplace. Distribution systems and even individual distributors are currently being asked to respond to customer's JIT requirements. To develop general theories for JIT application, it will be necessary to test many simulated forms. This study is one step in this process.

(2) How accurately the system can reflect the real world is partly a question of economics. The increased cost of a more detailed simulation must be balanced with the expected value of the additional information obtained (Maryanski 1980).

Two conflicting model attributes are realism and simplicity. The model should be detailed enough to incorporate the important aspects of the system, but it should not be so complex that it is impossible to understand and manipulate (Naylor et al. 1966). "Unfortunately, realistic models are seldom simple and simple models are seldom realistic" (Naylor et al. 1966). Increases in model detail and complexity may improve validity at the price of increased data input, programming time and computation time. Naylor et al. (1966) suggest that the objectives of the experiment also affect the level of detail required. In the JIT study the model level of detail is consistent with the general factor relationships to be investigated. That is, the JIT study's objectives involve the cost, profit and service performance of various configurations of physical distribution alternatives under various conditions of environmental uncertainty. To investigate these relationships, the model must consider data in sufficient detail to capture the factors which affect system performance. For example, if a simple fixed total average cost was used for a cost center, the affect of change in other variables (which actually do impact the cost center) would never be reflected. In the JIT study different treatments will impact the cost elements in cost centers and must be considered. Therefore, the JIT study will use a level of detail down to individual cost elements. This will be discussed in detail in the model description section.

(3) Naylor et al. (1966) also stated that stochastic computer output automatically satisfy the assumptions required for statistical data analysis.

(4) False confidence is mainly a problem when results are being interpreted by individuals who do not understand how they were developed. As with any decision support system results, the workings, assumptions and limitations of the model must be understood by those who would utilize it. The limitation aspect of this is the issue that the results of the study apply only to the range of conditions and JIT configurations investigated.

SUMMARY OF THE INTRODUCTION

American companies who choose among JIT optional configurations for adoption are doing so with little if any support from published quantitative studies. The purpose of this dissertation is to quantitatively investigate the effects of Just-in-Time in terms of system performance from a marketing perspective. This includes effects such as profit impact to channel members and distribution service levels maintained to customers. In marketing terms, logistics system performance is not limited to cost or profit considerations. It also includes measures of physical distribution service as it impacts service to the customer. It is also important to note the impact on all customers in the channel (the poor service performance of one member can impact subsequent members' service performance).

Research has established that physical distribution service (PDS) levels are important factors influencing customer need satisfaction and that these levels can be measured and should be set at levels which maximize total system profit (Perreault and Russ 1976(a)(c); Uhr, Houck, and Rogers 1981). Chapter II will review the details of the physical distribution service literature and attempt to show that across many products and situations PDS level is a key element in a firm's marketing mix which will be directly impacted by policy changes which affect distribution and production systems (such as the adoption of Just-in-Time). Although not always recognized, such changes which affect a firm's capabilities often involve important marketing considerations such as changed customer service expectations and needs. Beyond the changes in customer service, the Japanese system is also thought to reduce costs and improve product quality. To a marketer this all suggests the possibility of a significant differential advantage in the market place.

At this point it has been suggested that the decision to adopt JIT can be considered a marketing strategy decision which will likely impact profit and physical distribution service performance. To make a decision on adoption of JIT a marketing strategist needs to be aware of the relationship of JIT to profit and service performance.

ORGANIZATION OF THE DISSERTATION

To investigate the possible extent of JIT's differential advantage in the marketplace it is necessary to evaluate JIT options under a variety of typical operating conditions. Since it is not practical to test major system options on actual operating logistics systems, a computer representation of company operations will be used. Changes in system performance will be noted as Just-in-Time is applied to the physical distribution and materials management sides of the focal company, all in several environments of materials management operational uncertainty and demand uncertainty. The first step in this investigation (Chapter II) will be a literature review of the major areas involved:

(1) General Systems theory - to introduce the conceptual framework

(2) Just-in-Time - to introduce the independent variables

(3) Physical Distribution Service - to introduce the dependent variables

(4) Computer Simulation and Decision Support Systems - to introduce the proposed methodology

The next step, (Chapter III), will be a critique of past methodology and results where computer simulations of physical distribution systems have been used. These results will be shown to suggest the research hypotheses to be quantitatively investigated in this study. The next sections will include a description and justification of the chosen research design. Chapter IV will follow with the study's results, and Chapter V will provide an analysis and interpretation of the significance of the results.

CHAPTER II

REVIEW OF LITERATURE AND IMPLICATIONS

REVIEW OF LITERATURE

This chapter will consist of a review of past research studies which have contributed to theory, understanding and practice in areas which will form the basis for this study's research approach and hypotheses. These areas include General System Theory, Just-in-Time applications, measures of physical distribution channel performance, computer simulation and decision support systems.

GENERAL SYSTEMS THEORY

The terms "general system" and "general systems research" were introduced in a statement by von Bertalanffy in the 1930's (Klir 1978). In 1954 von Bertalanffy and other early proponents formed the "Society for the Advancement of General System Theory" to foster GST development.

The GST paradigm was initially suggested to be superior to the classical (Newtonian) approach primarily for studies involving biology, psychology and social science. Later evidence has expanded the GST domain by suggesting that certain properties of systems do not depend on the specific nature of the individual system, that is, they are valid for systems of different types (physical, biological, social). (Klir 1972).

While the classical Newtonian paradigm tried to derive the properties of the "whole" by scientific investigation of its isolated (noninteracting) components, the GST "systems approach" states that the "whole" should be studied not only by considering the components, but also the interactions of components among themselves and also between the system and its environment (Klir 1972).

Strictly speaking, GST is not a concrete theory in the formal sense (an axiomatic theory) (Klir 1972). "It is a conceptual paradigm in which many theories and concepts have been advanced" (Morris and Sirgy 1985).

GST can be characterized by describing its major components (Klir 1978):

1. General systems knowledge and methodology - a collection of concepts, principles, laws, theories and methods associated with general systems.

2. Basic general systems research - activities involved in further development (improvement, refinement, extension) of general systems knowledge and methodology.

3. Applied general systems research - applications of general systems knowledge and methodology to specific real-world problems.

The proposed investigation of JIT effects on channel performance investigation would fall under this last category of applied general systems research. Applying GST to marketing in general and channels in particular is not without precedent. Morris and Sirgy (1985) established a GST conceptual framework for channel research by applying four major systems concepts to distribution (cybernetics, feedback, conflict, and ecological niche).

The following application of GST to organizations by Beer (1980) also suggests that organizational environmental interactions should not be ignored.

1. Organizations are composed of components which are in interaction with one another while at the same time part of an identifiable whole.

2. Organizations usually have permeable boundaries and interact with the external environment from which they obtain energy, matter (people, electricity, money, raw material), or information as inputs and to which they export a product or service as outputs.

3. Organizations are a network of people, structures and processes that transform raw materials into products or services desired by users in the environment.

4. Organizations often have feedback mechanisms that allow components to adjust to other components, to the environment and to output performance.

5. Entropy suggests a running down of the system will occur when insufficient energy is imported into the organization and converted into outputs. On the other hand, energy beyond export requirements can be imported and stored in the system for later use.

This systems view of organizations considers uncertainty as an important environmental dimension. Beer (1980) also suggests that an organization may judge how favorably it is exchanging outcomes with its environment by economic (profit), service (distribution service), and quality of life measures.

It will be shown in Chapter III that this systems view can be applied to a JIT study by a simulation model that recognizes the existence of all relevant system components, considers their interactions, and acknowledges environmental effects. In the case of JIT, uncertainty in materials management and physical distribution are important real-world environmental considerations. Churchman (1968) supports this approach to organizational research by recognizing that demand lies in the environment of the system, because it is a "given" and because its nature influences system performance.

Further support is provided by Morris and Sirgy (1985) who specifically use automatic inventory reordering systems as an example of a self-regulating cybernetic (feedback controlled) channel subsystem. By applying GST to channel research Morris and Sirgy derived general propositions which will be further discussed in Chapter III as part of a GST foundation for many of the JIT research hypotheses.

The open-system theory of GST is applicable to any dynamic, recurring process, differentiated from but dependent on the larger stream of life in which it occurs and recurs (Katz and Kahn 1966). Katz and Kahn (1966) go on to state that the functioning of any open system consists of recurrent cycles of (1) input, (2) transformation and (3) output. The fit of the open system view with logistics can be seen by recalling that logistics concerns controlling the efficient flow and storage of materials and information into, through and out of an organization.

Knowledge of GST has enabled logistics theoreticians to rigorously examine the nature of logistics systems (Karrenbauer 1980). Heskett, Glaskowsky and Ivie (1973) made the following observations concerning logistics systems:

1. A logistics system possesses multiple interrelated parts.
2. The performance of one part affects and is affected by that of others; consequently, to analyze any subcomponent in isolation constitutes a serious methodological error.
3. The alteration of certain subcomponents generates more change in system behavior than others.
4. Overall system performance is dependent upon "balance" achieved among the subcomponents.
5. The weakest member often dictates the upper bound of system performance.
6. Optimum system performance is often not dependent upon the optimal performance of each subcomponent, but requires balance and coordination among them.

Bowersox (1979) stated that " the systems approach provides an analytical framework within which the design and administration of movement systems can be quantified."

Any analysis of JIT as a logistics strategy must be approached from the general systems approach of considering its effect on the total system's performance. Bowersox, Smykay, and LaLonde (1968) described the systems concept as "one of total integrated effort toward the accomplishment of a predetermined objective." He goes on to state that "it is the performance of the total system which is singularly of importance. Components only exist and find justification to the extent that they enhance total system performance. Components need not have optimum design on an individual basis."

While this total system approach is basic to logistics research, it is not basic to the investigations of all disciplines (e.g., Management Science and Operations Research). Research will be reviewed in later chapters which did not recognize the necessity for a systems approach to logistics strategy evaluation. Their results will be shown to be the optimizing (or investigation) of only one subsystem performance component in a complex, interdependent, integrated system (e.g., to investigate JIT production in isolation from its interaction with other systems such as order processing, transportation, and customer service). Results from these non-systems approach studies may only represent part of the complete system response.

LaLonde and Zinszer (1975) also noted that the demands of the modern business environment would require companies to utilize the systems approach to management. That is, companies must consider the dependence and interrelationships of all company elements, (materials management, production, distribution, ...) and optimize the total system performance rather than the individual element performance. Karrenbauer (1980) also reviewed the system theory literature and demonstrated how it could be applied to physical distribution systems, noting that, "the systems theory tenet of interrelationships among constituent entities has provided the fundamental theoretical basis for integrated logistics management in general and its corollary, the total cost concept, in particular." This approach was also suggested by Gregson (1976/1977) when he stated "there is evidence, therefore, to suggest that company logistics may be represented as a system, in that it portrays a total pattern of phenomena whose components are interrelated, and it demonstrates the system's main features of process, inputs, outputs, feedback and constraints." As these researchers and the systems approach suggest, logistics systems must be analyzed as part of the whole system which is functionally integrated.

Ballou (1973) identified the logistics subcomponents which interact and require trade-offs to be made as transportation, inventories, customer service, order processing, warehousing, materials handling, packaging, scheduling, and facility location. Similar views by other logistics researchers suggest that "systems thinking" and the similar "total cost concept" and "integrated logistics system" have been fundamental to logistics study. While the "total cost concept" takes a somewhat closed system view, the "total profit concept" recognizes environmental interaction and is now considered to be a superior systems approach. The proposed research will use total profit and physical distribution service level as indications of performance as part of a total system approach to the investigation of JIT's impact on channel performance.

JUST-IN-TIME

In a truly competitive global market place, success will go to the supplier which is best able to meet customer needs. Japanese producers have consistently shown themselves capable of meeting market needs, particularly in terms of price and reliability. Investigation has suggested that Just-in-Time (Kanban) inventory control and production systems are important elements in Japan's competitive advantage (Huang, Rees, and Taylor 1983). Understandably, several U.S. industries, (notably the automotive, appliance, and business machine manufacturers) have adopted systems patterned after the Japanese (Hahn, Pinto, and Bragg 1983).

The terms Just-in-Time and Kanban have come to be perceived in a variety of different ways depending on organizational perspective and channel position. Some of the variety of definitions and connotations which JIT has developed include; "delivery of the optimum quantity at the optimum time; ...a working relationship among vendor, carrier and user with the common goal of taking all the excess stock out of the inventory pipeline; ...no early shipments and no late shipments; ...a flexible manufacturing approach that allows quick response to changing needs" (Quinn 1984).

From the perspective of a transportation supplier JIT would seem to be a system of frequent deliveries with tight arrival times. An industrial buyer would see mainly the new relationships with sole source suppliers and reductions in inventories. Similarly, a production manager would see JIT as characterized by a flexible manufacturing approach. To an OEM manufacturer JIT may be seen as a improvement in its materials management system while its suppliers may see JIT as a significant increase in distribution service requirements. Each of these perspectives can be viewed as non-systems thinking about JIT. For the purposes of this research, Just-in-Time (Kanban) will be viewed from the total system perspective and the term JIT will be used to represent an integrated logistics system characterized by inventory-less production and induced material flow, (i.e., material which is pulled rather than pushed through the system). For the remainder of this dissertation the concept of such a system will be indicated by "JIT".

Robert B. Stone (1982), General Motors Corporation Vice President of Materials Management, noted that JIT is the reverse of the inventory management and production control system traditionally used in American industry. While the American system pushes material through the pipeline based on schedules and forecasts, the JIT system pulls material through the pipeline based on what is actually built.

In a pull system, each succeeding stage in manufacturing demands and withdraws in-process units from the preceding stage at exactly the rate it is consuming them (Huang, Rees, and Taylor 1983). Each stage is thus supplied "Just-in-Time" with only its immediate needs. No manufacturing can occur (and thereby no inventory is produced) without an authorization indicated by the next stage's consumption. For example, this can be done by a container system with each container holding a small quantity. As the container is taken to be processed by Operation (b) an inventory control card (called a Kanban in Japan) is removed from the container and passed back to Operation (a). On receipt of the Kanban, Operation (a) is authorized to process one more container to replace the one taken by (b). From raw material to finished goods the system is driven by the demand for the final product and operates with inventory tightly controlled to a minimum (Huang, Rees, and Taylor 1983).

Although many would consider JIT a Japanese innovation, early physical distribution literature in the United States recognized the pull system option. Bowersox, Smykay, and LaLonde (1968) described a "zero-response" inventory system as "a highly responsive information system linked to rapid communications and cycled deliveries ...(which) replaces inventory rapidly as it diminishes." Thus, JIT approaches could have been used earlier by American industry, but it was not until the 1980's that rising interest rates made the cost of carrying inventory prohibitive and improvements in computer technology made controlling complex systems practical.

While the most well known objective of JIT is the elimination of inventory, JIT should be viewed as part of a total system which is characterized by several common elements, each dependent on the efficient functioning of the others. Typically, these include a "centralized commodity management" program involving corporate wide purchasing at long term, fixed (non-order volume dependent) prices from a reduced supplier base characterized by single sources, and pull initiated (Kanban) production with small lot sizes, quick set-ups, zero defects process control, integrated channel telecommunications, and dependable transportation modes that arrive within narrow time windows and which minimize receiving materials handling (Mentzer and Gomes 1985).

To better understand the research objective of this dissertation, it may be helpful to consider the 2 x 2 typology of JIT Research represented by Figure 1. This typology suggests that JIT research can be categorized according to two factors, (1) the researchers' approach and (2) level of analysis used (Gomes and Mentzer 1988). Approach in this case refers to the researchers' choice of either a conceptual study (without empirical testing) or a study which does use empirical testing of some hypothesis (or some other mathematical analysis). Both conceptual and empirical studies can be done at two levels of analysis (1) total systems approach and (2) a non-total systems approach. For the purposes of a JIT study a total systems approach would involve noting the corporate wide or channel wide effects of a JIT strategy. A non-total system approach would involve consideration of just the effects relating to some subsystem, typically manufacturing, purchasing, or distribution.

The use of a typology to categorize JIT research creates a map which represents the entire area of JIT study. This map can be used to position past research and recognize areas which have received high or low attention. It will also illustrate where the proposed study stands relative to past research. With such a typological map to establish a frame of reference the JIT subject area becomes organized and more amenable to systematic investigation.

Figure 1 indicates a major gap in JIT research conducted from a empirical/total system perspective. The reason for this gap may be that the tools of total system research usually involve complex methods such as mathematical functions or simulation models. Researchers not familiar with these methods are often limited to conceptual decriptive studies. Researchers that do utilize mathematical or simulation approaches tend

		Research Approach	
		Conceptual	Empirical
Level of Analysis	Non-System	Jackson and Morgan (1983 Finch and Cox (1986)	Huang Rees and Taylor (1983) Kim (1985) Piper and Radford (1985) Bookbinder and Locke (1986) Lulu (1986) Philipoom (1986)
	Total System	Ebrahimpour and Schonberger (1984) Rosenberg and Campbell (1985)	

JIT RESEARCH TYPOLOGY

Figure 1

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to be specialists interested in studying a specific subsystem response. This explains the many empirical/non-system studies shown in Figure 1. For example, a management science researcher investigating JIT production without consideration of the impact on raw materials suppliers, other products being produced, or physical distribution would be typical.

The conceptual/nonsystem category would include the great number of JIT articles which appear in trade publications (only journal articles are shown in Figure 1). A discussion of JIT in a purchasing, accounting, or transportation publication would review only those effects of interest to its audience. Only a very few conceptual studies have considered the total system effects of JIT.

Thus, a typology of JIT research has been suggested which indicates a major gap in empirical/total systems studies. The reason for this gap may be that a simulation model which represents a total system or channel is a very complex instrument. Few models of this type exist outside of the planning offices of major corporations. A major contribution of this proposed research will be to approach JIT from this empirical total system perspective.

The following sections provide a brief review of each of the journal articles positioned in Figure 1. The information contained in the review provides support for the grid position on the typological map.

Huang, Rees and Taylor (1983) simulated a JIT with Kanbans in a multiline, multistage production system to determine the adaptability of the Japanese system to a production environment characterized by variable processing times, variable master production scheduling and imbalances between production stages. Variability in processing times and demand rates were shown to impact average overtime and production output. In the simulation, variability in processing times and demand were amplified and resulted in even larger swings in overtime. The results indicated that success of a JIT system will be dependent on reducing processing time and demand variation. The authors suggested that if these conditions can not be met in a firm's business environment, they may be better off with a non-JIT system.

While the findings concerning the effects of variable processing times do agree with the common understanding of JIT, the response to demand variation does not. It will be argued later (in the hypotheses section), that the simulation model was restrictive and did not fully represent the flexibility (typical in a Japanese system) which would have allowed it to adapt to demand changes.

Jackson and Morgan (1983) presented a brief overview of JIT production along with a few anecdotal references to typical JIT results in application. The authors noted that the literature in the JIT area is almost purely descriptive. The main body of the study deals with several brief discussions of JIT production research issues.

Suggestions for future research included JIT as a diffusion of an innovation issue, the attitudes and perceptions at various channel levels, JIT system design alternatives, Material Requirements Planning vs. JIT, and behavioral and cultural issues. The main conclusion of this study was that JIT is a very rich area for researchers, it will be of interest to many disciplines and should be approached with multiple methods.

Ebrahimpour and Schonberger (1984) briefly explained JIT and Total Quality Control (TQC) and attempted to show the potential for the approaches in developing countries. The authors suggested that as important as JIT may become for Western industrialized countries it may hold even greater promise for developing countries. The problems indigenous to developing countries were listed along with how the utilization of JIT/TQC would solve the problems.

Although the authors make an interesting presentation they never legitimized their contention that JIT can work where a conventional system failed. Problems that exist (e.g., unreliable lead times, shortages of raw materials, inadequate maintenance, lack of appropriate supervision, and low quality) may have underlying causes that go too deep to just suggest JIT as a solution. The total of the developing country problems listed represents the antithesis of JIT. Under JIT the worker is responsible for much more, machine change-overs, quality control, maintenance, and is self supervising. If developing country systems and workers have not solved the listed problems under conventional systems it is hard to understand how they can assume the additional demands of JIT.

Kim (1985) introduced the concept of replacing the manual Kaban operating system with an equivalent computerized information flow "Periodic Pull System" (PPS). It was suggested that the computer system is superior due to shorter response time. The author did not acknowledge a manual Kanban system's simplicity, elegance, and ease of understanding nor did he actually test the total cost of the alternative approaches. Kim's major contribution was the presentation of a mathematical model of a single product multi-stage series process operating under PPS. This model could be the first step in the creation of a production simulation model which could then be used to evaluate the real advantages of the Kanban process.

Piper and Radford (1985) used the SLAM simulation language to represent a Kanban production control system. The number of units in each container was varied under two levels of availability. Results indicated that, (1) reducing work-in-process (WIP) does reduce the throughput but not until WIP drops unusually low, and (2) increasing availability greatly increases throughput.

Rosenberg and Campbell (1985) discussed JIT as a subset of channel management. This approach recognizes that JIT is part of an integrated system with behavioral as well as material interfaces. This integration requires trade-offs between traditional business interests (manufacturing, physical distribution, finance, and marketing). Although limited in depth, the research did present an important concept - JIT as a channels issue.

Bookbinder and Locke (1986) conducted a simulation analysis of a JIT distribution system. In one model, warehouses held stock and in the second model warehouses only served to "break-bulk." The remainder of the channel was the same (one factory supplying two warehouses and each warehouse supplying three retailers). Under identical demand the "break-bulk" warehouse model was determined to be superior. It provided essentially the same distribution service level while carrying one less echelon of stock.

Finch and Cox (1986) examined the application of JIT in a small manufacturing setting. A case study of a bottling company was used to show that not all aspects of JIT are suitable to smaller operations. In an automated continuous flow process, Kanban is not applicable, but quick change set ups and JIT delivery of raw materials would be an advantage. The value of this advantage was not explored empirically. How the bottler could arrange for JIT delivery (in the face of very low channel power) was also not considered.

Lulu (1986) utilized a simulation model and ANOVA to demonstrate that if a individual process is subject to random failure, increases in work-in-process (WIP) will only increase production rates up to a specific threshold. Lulu found that the principal factors which increase production rates under JIT are minimized process downtime and preventive maintenance, not the introduction of WIP.

Philipoom (1986) used a Q-GERT simulation language model to test the extent that the Kanban approach to production control can be used successfully in American manufacturing systems which combine assembly and job-shop type operations and exhibit high degrees of system variability in processing time, work station utilization and throughput velocity. He found that JIT with Kanbans can be used even when machine utilization is high and with high variability if sufficient inventory is carried. The carrying cost of this extra inventory may reduce profit to the point that a conventional Materials Requirement Planning (MRP) approach to production control may have produced a more profitable solution than the Kanban option. One of Philipoon's other findings was that inventory and set-up costs must be weighed against each other rather than simply seeking to minimize the inventory level. The MRP vs. Kanban comparison was not tested, however.

This brief review of the JIT literature has indicated a theoretical and methodological research gap (JIT approached from the perspective of GST and total system simulation) to which this dissertation is directed.

PHYSICAL DISTRIBUTION CHANNEL PERFORMANCE

The preceding section introduced the concept of JIT and how different JIT configurations may be used as independent variables. This section will consider response variables which can be used to measure system performance under various treatment conditions. From a marketing perspective, physical distribution service is an important indication of a firm's performance.

The term physical distribution system was introduced in Chapter I as concerning the movement of products from producers to customers. A measure of the performance of this system (and of the whole system) from the customers perspective would be the physical distribution service level maintained. The remainder of this section will review the identification of PDS elements and the justification of particular ones to be used as dependent variables.

Stone (1982) noted, "very simply, the Just-in-Time (Kanban) system provides that only the right parts in the right quantity are produced at the right time." Mentzer and Schwartz (1985) defined physical distribution service (PDS) as "providing the right product at the right place at the right time." The similarity of these definitions suggest that JIT and PDS are interrelated. That is, successful JIT systems should produce high levels of PDS. It has been established that there are different JIT configuration options available to the marketing strategist. It would be of value to this decision maker to know the likely PDS impact of these options. This suggests research with JIT configuration as a independent variable and PDS level as a dependent variable.

Perreault and Russ (1976 c) viewed physical distribution service more generally as "the interrelated package of activities provided by a supplier which creates utility of time and place for a buyer, and insures form utility." From this it can be suggested that physical distribution service is a subset of the broader concept of customer service.

Customer service has been defined by La Londe and Zinszer (1976) as "a customer-oriented corporate philosophy which integrates and manages all of the elements of the customer interface within a predetermined optimum cost service mix." They also note that while customer service is a universally used form, it is individually defined. What is an important customer service element to one company may not hold the same importance for another. The same can be said of physical distribution service and the relative importance of its elements.

Studies by Gilmour (1977) and Levy (1978) have shown physical distribution service elements to be key elements of customer service. Willett and Stephenson (1969) established the ability of buyers to correctly perceive different levels of customer service elements important to them.

Perreault and Russ (1974), noted that rather than attempting to minimize physical distribution cost, firms should recognize the relationship with sales and utilize a total systems profit maximization approach. They specifically linked physical distribution to the "marketing concept" stating that "physical distribution service packages should be derived from the customers' needs." This, they suggest, is reflected in the need for product availability, accuracy in shipments, good arrival condition of shipments, and the length and variability of the order cycle. These are the PDS elements which affect demand. The objective of the PDS research stream from this perspective was to establish the importance of physical distribution service and identify its elements, rather than to suggest a model of purchasing behavior in terms of PDS.

For a methodological outline of the PDS research stream one could adapt Christopher's (1983) customer service policy framework to PDS which yields the following managerial approach : (1) identify key components of PDS, (2) establish relative importance of each component to customers, (3) identify present element performance vs. competition, (4) segment the market by service requirements, (5) design the physical distribution service package, and (6) establish measurement and control procedures.

To carry out such a program, Mentzer, Gomes, and Krapfel (1989) suggested that three indicators are available for the PDS construct, (1) availability (percent of orders, lines, or units completely filled), (2) timeliness (order cycle time central tendency and variability) and (3) quality as reflected by the arrival of the right quantity of the goods in acceptable condition. These are measurable elements well suited for use as dependent measures, but further review and integration will be necessary to confirm Mentzer, Gomes, and Krapfel's suggestion.

Physical distribution, as a specified field of study, is commonly perceived as beginning in the early 1960's. Physical distribution concerns, however, are as old as commerce and have been mentioned throughout the development of marketing thought. John C. Crowell (1901), for example, wrote in detail on the distribution of farm products for the U.S. Government. By 1911 Ralph S. Butler was teaching from his early text entitled Selling, Buying, and Shipping Methods. In Shaw (1912, 1916) the concept of the strategic use of distribution was introduced. Shaw discussed the basic functions of a business in terms of motion, motion changing form called production, and motion changing place and ownership which he labeled distribution. Generalizing this view, Shaw defined business itself as "material in motion" (Shaw 1951). Fred Clark (1922) more clearly outlined the role of distribution in marketing. By the late 1920's, the term physical distribution was in use in its modern context (Borsodi 1927). Thus, distribution was recognized as part of marketing prior to Neil H. Borden's popularization of the concept of marketing mix "ingredients" which began in the late 1940's (Borden 1964).

After World War II, military logistics was integrated with the new business philosophy termed the "marketing concept" (Lambert and Stock 1982). This implied a customer rather than a company orientation towards distribution. In the early 1960's physical distribution was established as a specific field of study. Physical distribution researchers borrowed applied analytical methodology initially from economics, and later from systems theory and operations research.

In 1961 Smykay, Bowersox and Mossman authored one of the first texts devoted specifically to physical distribution emphasizing the systems approach and total cost concept. Perreault (1973) investigated the role of distribution service in purchasing decisions, and LaLonde and Zinszer (1976) followed with the first comprehensive investigation of the customer service function in major corporations. While the relationship of customer service (and its subset, physical distribution service) had been related to sales, it was not until Uhr, Houck, and Rogers (1981) that the relationship with profit was measured.

To study distribution the systems concept must be applied to the whole corporate operation, not just to a closed (non-interactive) physical distribution system. To understand the total impact of a change to a distribution system (like JIT), the researcher must be able to asses the impact on the marketing system which it is imbedded in, the impact on parallel systems, and even the impact on the next higher corporate system.

The intent of this research is to utilize a total system simulation (the systems concept applied to the entire material flow) to measure the effects of a particular inventory and process control strategy. The effects of this strategy on profit performance will be measured directly, but it is of further interest (from a marketing management perspective) to investigate the impact on physical distribution service levels.

The remainder of this literature review will seek to establish the importance of physical distribution service by integrating the literature stream initiated by Perreault (1973) and LaLonde and Zinszer (1976). Because of the shortage of research in this area, all studies using quantitative methods were included and conceptual studies were, therefore, excluded.

The most significant PDS stream is represented by Perreault (1973) and the Perreault and Russ (1976)(a)(b)(c) series, and Luce (1982) who attempted to expand Perreault's findings to Brazilian industry. As opposed to research streams which have many good studies measuring the same relationship (e.g., price vs. quality, salesperson characteristics vs. performance), physical distribution service has few. Most of these existing studies investigate different relationships with different hypotheses. Therefore, the results can not be directly integrated. That is not to suggest that the studies could not be grouped in some manner to consider the implications of the whole effort.

Several of these studies have developed a ranking of factors important to the purchase decision as a first step in testing various hypotheses. Typical methodology in this area would be:

(a) contact a sample of industrial buyers and ask them to rank the importance of a supplied list of PDS elements

or

(b) with interviews, develop a large list of PDS elements; then through a questionnaire applied to a large sample use factor analysis to arrive at key elements

then

(c) after (a) or (b) use analysis of variance to test if different elements are important to different industries.

The plan of this review is to extract the rankings and consider some manner of combining them. This is clearly taking liberty with traditional quantitative methods. Any combination would be averages of averages and would involve concerns for weighting methods and a major question of the meaning of the results when completed. Because PDS is an immature research stream, much of the research is exploratory. This being the case, the present study will try to make some use of the data that is available, even if the method of combination and the results are exploratory.

The investigation of the relationship of JIT to channel performance will require measures of that channel's performance. The measures used will be profit and PDS. If PDS can be measured by elements that are important across industries, the external validity of the study will be increased. Thus, the combination of results across many researchers, industries and products is desirable.

Results of the Integration

Since the importance of physical distribution has been shown to be product and company specific (LaLonde and Zinszer 1976), it would not be correct to weight results by sample size. Further, the objective of this section is to establish the importance of PDS across all studies. Therefore, each study will be given equal weight.

Of nine studies considered, six ranked several factors which affect the purchase decision (PDS being one) and two ranked just the elements of PDS. One study ranked both. All of the factors considered in the studies were listed and points were given each based on where it was ranked in each study (each first place occurrence five points, each second place four points, and so on). The sum of these points provided the total ranking of PDS elements within customer service in Table 1, and the ranking of only the PDS elements in Table 2. For example, if delivery time was ranked first in three studies (and not ranked in any other) it was assigned fifteen points and placed on Table 1 ahead of other factors with less points. The point totals have been left off Tables 1 and 2 to avoid the illusion that the ranking scheme provided anything beyond a very general indication of what factors were important across studies. This method does not allow a firm statement of which factor is first, second, or twice as important as the next. It only suggests which factors are of general importance because they appear often in studies that do specifically rank.

The details of each study are shown in Table 3.

PDS Literature Details

Jackson, Keith, and Burdick (1986) examined the perceived relative importance of six physical distribution service components and how the importance varies across five product types and three buy classes.

Purchasing agents from 25 large manufacturing firms were randomly assigned to one product type and one buy class condition. Questionnaires were distributed which presented a role-playing scenario for the assigned treatment condition. Based on the scenario the subject was asked to allocate 100 points among six distribution service elements.

The experimental design was a repeated measures design with two factors: product type with five levels and buy class with three levels. The repeated factor was distribution service which had six levels. MANOVA indicated that the relative importance of distribution service did vary across product types, but not across buy class types.

Table 1

Importance of Physical Distribution Service
in Supplier Evaluation and Purchase Decisions

General Physical Distribution Service
Delivery Reliability
Delivery Time
Product Availability
Quality and Price
Sales Service and Policy
Technical Ability
Product Performance
Location

The Bonferroni multiple comparisons procedure was used to investigate differences among cell means. The results supported earlier research which found order cycle time and in-stock performance to be important physical distribution service elements. No differences were found based on size of firm or industry type.

THe importance of the Jackson, Keith, and Burdick study for this paper is that although PDS importance varies across product types, ele-

Table 2

Importance of Individual Physical Distribution Elements

Order Cycle Time

Percent Lines Filled

Order Cycle Time Variability

Accuracy in Filling Orders

---

ments such as consistency of delivery, in-stock performance, and lead time stand out as generally important across many products.

Luce (1982) surveyed the opinions of purchasing managers (located in two industrial areas in Brazil) on the subject of physical distribution service. Luce identified 418 companies (180 responded) which employed more than fifty workers in either the metallurgical, mechanical, electrical, transportation equipment, furniture, plastic or shoe industries. The data collection instrument was a questionnaire which covered the buyers' evaluations of suppliers' PDS, the importance of PDS, the factors influencing purchasing decisions, attitudes about specific purchasing decisions, and company, respondent and product information. One section involved the ranking of PDS elements. The results of the request to rank in order the 5 most important PDS elements from a given list are shown in Table 3. The final ranking was done by a Wilcoxon matched-pairs signed test conducted for every difference between mean ranking.

Table 3
Literature Rankings of PDS Elements
and Ranking of PDS as a Purchasing Factor

1.	Authors (date)	Jackson, Keith, and Burdick(1986)	Luce (1982)	Christopher et. al. (1979)
2.	Research Design	Survey	Mail Survey	Interview
3.	Research Question	Perceived relative importance of PDS components	To measure the importance	Why do customer's perceptions of customer service vary
4.	Origin of PDS Factors Used	Discussion with Purch. Agents and literature review	Previous research	Interviews
5.	Sample Characteristics	Purchasing Agents at 25 large industrial firms in 3 states	Brazilian purchasing managers in two cities at companies with > 50 employees	Food chain buyers and managers
6.	Sample Size	254	276	small sample
7.	Sampling Technique	Non-random	All companies in telephone directories	not stated
8.	Task	For a given scenario allocate 100 points among six PDS elements	Rank importance on 1-5 scale	Rank suppliers, rank criteria used to evaluate
9.	Data Analysis	MANOVA and Bonferroni multiple comparisons procedure	Wilcoxon matched pairs test for differences between means	Spearman rank-order correlation coefficient
10.	Ranking of PDS Elements	1. Consistent delivery 2. In-stock 3. Lead time 4. Cooperation 5. Order process information	1. Accuracy in filling orders 2. Average delivery time 3. Rush services and billing 4. Action on complaints 5. Order status information	
11.	Ranking of PDS as a Purchasing Factor		1. Quality 2. Price 3. PDS 4. Location 5. Min. Order Size	1. Product availability 2. Promotional activity 3. Representation 4. Order status 5. Distribution method

Table 3 (continued)

Levy (1978)	Anderson, Jerman and Constantin (1978)	Gilmour (1977)	Mathisen (1977)
Mail Survey	Mail Survey	Field survey	Mail survey
Identify relevant elements of	Perceived importance of PDS Goals	Importance of customer service factors in vendor selection	The relevance of business logistics service variables in the purchase process
Previously developed list	Previous research	Previous research	Exploratory research
Drug wholesaler executives	Non-academic members of NCPDM	Suppliers and customers in the scientific instrument and supplies industry	Contractors and consultants who purchase or influence purchase of commercial air conditioning equipment
108	370	40	166
Not stated	All non-academic members	Non-random	Stratified random sample from 15 major metropolitan areas
Pairwise matrix trade-off	Pair comparison--constant sum to 100	Rank factors by importance and rank top 5	Rank on 5 point scale
Conjoint analysis	Mean scale value	Mean ranking	Mean ranking
1. Fill rate 2. Terms of sale 3. Lead Time 4. Order placement policy 5. Consistent delivery	1. Order cycle time reliability 2. Percent orders filled 3. Min. PDS cost 4. Min. order cycle time 5. Min. damage in transit	1. Availability 2. After sales service 3. Delivery reliability 4. Delivery time 5. Technical competence of rep.	1. Sales service 2. Operating life of equipment 3. Distribution service

Table 3 (continued)

Perreault and Russ 1976 (c)	Zinszer (1976)	Cunningham and Roberts (1974)	Wind, Green, and Robinson (1968)
Mail Survey	Mail survey	Field Survey	Lab Experiment
Determine importance of PDS relative to other factors in purchasing decisions	Indicate relative importance of customer service elements	Identify the determinants of supplier choice	What are the determinants of vendor selection
N.A.	Previous research	Researchers, literature, and interviews	interviews with ten buyers
Member Purchasing Managers of National Association of Purchasing Management	Manager members of NCPDM	Valve and pump industry buyers	Purchasing agents at one firm
216	112	25	20
Random	Not stated	Not stated	Not stated
Rate importance in supplier selection	Allocate 100 points to elements important to business	Given 13 factors, pick and rank top five	Assign most important 100 Assign least important 0 Assign remainder in between
Mean across 6 products	Komogorov-Smirnov	Percent times in top five	Thurstonian scaling
1. Quality 2. Distribution service 3. Price 4. Supplier management 5. Distance	1. Product availability 2. order cycle time 3. Distribution flexibility 4. Distribution information 5. Distribution malfunctions	1. Delivery reliability 2. Technical advice 3. Test facilities 4. Replacement guarantee	1. Quality/price ratio 2. Delivery reliability 3. Technical ability 4. Information and market services 5. General reputation

Table 3 (continued)

Dickson (1966)
Mail Survey
Identification of factors important in vendor selection
Survey
Members of National Association of Purchasing Managers
170
Random
Rank factors 0-4 for four product/firm cases
Mean rating
1. Quality 2. Delivery 3. Performance 4. Warranties 5. Facilities

Other research questions were addressed by several ANOVA and MANOVA analyses. The following hypothesis was found to be statically supported at $\alpha = .10$:

> "the greater the average order cycle time, the greater the importance of PDS in selecting suppliers"

Hypotheses which suggested some directly proportional relationship between the importance of PDS in selecting suppliers and number of deliveries, percentage of back orders, average order cycle time and company size (sales or employees) were not statistically supported.

Additional hypotheses that were not supported include:

> "the greater the number of alternative suppliers, the greater the importance of PDS in supplier selection"
>
> "the greater the satisfaction with PDS, the lower its importance as a purchasing factor"

The significance of the Luce study for this dissertation is as support for the overall importance of PDS and an excellent ranking of PDS factors.

Christopher, Schary, and Skjott-Larson (1979) suggested that the customer's perception of customer service will vary by the type of organization and the role position of the respondent. Through standardized interviews of food chain buyers and managers, customer service factors were rank ordered by the respondent's perception of their importance in supplier performance evaluation. In their responses the customer representatives did not separate physical distribution activities from other variables of the marketing mix. While the distribution factor "product availability" was ranked number one, marketing factors "promotional activity" and "quality of representation" were ranked second and third.

The position of the respondent in the organization was also shown to have a significant influence on the factors chosen as important and their rankings. Buyers appeared to perceive customer service differently from other members of their organization. Buyers tended to attach more importance to product availability.

For managers, the results indicate that service is situation specific. Suppliers must know the values of their customers as industries, organizations, and as individuals.

Levy (1978) conducted a mail survey of 425 manufacturers and wholesalers in the over-the-counter pharmaceutical products industry. Sixty-six responses were received from wholesalers and forty-two from manufacturers. The wholesaler questionnaire requested information on the wholesalers' perceptions of their suppliers' (the manufacturers) service performance. The manufacturers' questionnaire requested information on their perception of the importance of each service to their wholesalers. Factor analysis was used to determine the underlying structure of relevant customer service elements. Discriminant analysis was used to determine which customer services are perceived differently by wholesalers and manufacturers.

To determine the relative importance of customer service elements, fifty wholesaler executives were telephone surveyed and asked to rank from 1 to 9 each cell of a matrix which crossed the service levels of two customer service elements. Each respondent ranked ten combinations.

Through conjoint analysis the following was investigated:

1. the relative importance of the customer service variables.
2. the perceived monetary value of these services.

The results of the rank ordering of the customer service elements in terms of perceived dollar value are reported in Table 3.

Anderson, Jerman and Contantin (1978) investigated the relative importance of physical distribution goals (elements). A mail survey of 1511 non-academic members of the National Council of Physical Distribution Management resulted in 397 responses for the hierarchy of goals section. Goals were ranked for importance by a paired comparison constant sum to 100 scale procedure. Each respondent completed 20 paired comparisons which were converted to an interval scale and the mean values used for the goal ranking. The results of the ranking can be seen in Table 3.

Multivariate analysis of variance was used to investigate differences in goal structure by respondent job title. The job title relationship was found to be non-significant. For this dissertation, the relevance of this finding is that the importance of goals (essentially PDS elements) is the same whether the respondent is top or middle management.

Gilmour (1977) examined the service provided by the major suppliers in the scientific instrument and supplies industry in Australia. In a series of field interviews, Gilmour collected data from 32 customer organizations (11 private; 5 government, 5 secondary schools, 7 universities, and 4 hospitals). Data from 6 suppliers (8 subjects) was also collected. The 6 suppliers represented essentially the whole supplier industry but the 32 customers represented a sample non-randomly chosen from the customer universe.

Each respondent was shown a list of 17 customer service elements and asked to rank order the five most important for this industry. The average importance of each of the nine most mentioned elements was noted for all customers, for all suppliers and for each of the five types of customer organizations. The 5 most important elements for all customers are shown in rank order in Table 3.

There was some difference of ranking by segment which indicates a possible benefit for applying different customer service policies in different segments. There were also enough differences between supplier responses and customer responses to support the need for this type of research.

The significance of these results for this dissertation is in the similarity of the element importance ranking across the five customer groupings. For example; 4 of 5 rated Availability as most important; 2 of 5 rated after sales service second while 1 rated it first; 5 of 5 rated delivery reliability third or fourth.

Mathisen (1977) investigated the relevance of logistics service variables in the industrial air conditioning purchasing process. From a universe of 800 executive officers of mechanical contracting and consulting engineering firms a geographically stratified random sample was taken from 15 major cities. A mail survey resulted in 166 usable responses. The first section of the questionnaire asked respondents to assess how much control they feel they have over purchasing decisions.

Section two asked for a 1 to 5 importance rating to be assigned to each of 19 factors which may impact the purchase decision. Sections 3 and 4 dealt with brand specific questions and respondent and firm characteristics.

Factor analysis reduced the 19 purchasing factors to 4 and a mean importance rating was calculated for each. Discriminant analysis was used to test the significance of factor importance profiles across segments. The results did indicate that the importance of logistics service factors varied by market segment. The overall importance ranking results can be seen in Table 3.

Perreault and Russ (1976c) examined the role of PDS (i.e., the importance of PDS, the determinants of its importance, and the determinants of purchaser satisfaction with it) in industrial purchase decisions. A mail questionnaire was sent to a random sample of 400 members of regional associations affiliated with the National Association of Purchasing Management. From 216 responses the mean importance rating for supplier characteristics were found. The aggregate results (across all products) of the top 5 important supplier characteristics are shown on Table 3.

The respondents were asked to make their replies product specific (i.e., pick one product type - semiconductors, bearings, acid, sheet plastic, fasteners, and lubricants - which the firm purchased).

The results showed that relative importance of supplier characteristics varied widely across the six products. Only Quality and PDS were consistent as first and second most important across all products.

The authors went on to investigate PDS further by asking respondents to indicate on a seven point scale their satisfaction with 9 aspects of PDS received from their suppliers. The results indicated that there was most satisfaction with billing procedures, order methods, and accuracy in filling orders. The least satisfaction involved delivery time and delivery time variation. The importance of Perreault and Russ for this dissertation is an additional example of the importance of PDS across products and industries.

Zinszer (1976) mail surveyed a management level sample of National Council of Physical Distribution members to determine if the relative importance placed on the elements of customer service differ by industry. The industries represented included manufacturers of chemicals, food, pharmaceuticals, electronics, paper, machine tools, and merchandisers of consumer and industrial products. The results of the study indicated that significant differences do exist across industries. The differences were found to be related to the specific nature of the distribution system and product flow.

As a first step in the study, respondents were asked to rank marketing mix elements and customer service elements by their importance to business. Customer service was ranked the second most important variable in the marketing mix (after product quality). For the elements of customer service, product availability and order cycle time were judged most important across industries.

Cunningham and Roberts (1974) examined the role of customer service in influencing industrial buyer behavior. The products considered were steel castings and forgings being supplied to the valve and pump manufacturing industry. The industry universe consisted of approximately 25 steel casting suppliers, 15 steel forging suppliers, 70 pump industry purchasing points and 100 valve industry purchasing points. A field survey was conducted which covered 13 of the larger pump industry purchasing points representing between 75 percent and 90 percent of the total pump demand. Twelve valve industry purchasing points were interviewed representing between 75 percent and 85 percent of the valve demand.

The 25 buyers were asked to name the five most important service factors and to rank them in order. Service factors were then compared by three criteria, (1) times mentioned, (2) times ranked in top 5, and (3) times ranked first. By all three criteria delivery reliability was indicated to be the most important. The combined results are indicated on Table 3.

It was also found that 80 percent of the buyers formed a favorable impression of suppliers (leading to purchase patronage) based on the suppliers' ability to meet the buyers' need for, (1) quality, (2) service, and (3) price. The nature of this market was such that suppliers had to rely on non-price factors to compete.

<u>Wind, Green and Robinson</u> (1968) attempted to determine the relative importance of determinants of industrial buyers' vendor selection. Twenty subject buyers from one manufacturing firm were presented with a hypothetical vendor whose performance was described by a set of 3 characteristics (out of a list of 10 total) each with a (poor or ideal) dichotomous rating. The subjects were asked for the overall worth of the

given combination of characteristics between zero and 100. Results were analyzed by configural scoring and regression analysis.

Subjects were also asked to consider the whole list of 10 vendor characteristics and assign 100 to the most important, zero to the least important and proportional values to the reminder. These results were analyzed by Thurstonian scaling techniques. The ratings were tested for interjudge agreement by computing Kendall's concordance measure which was found to be highly significant (F = 34.68). This indicates agreement among the buyers as to the ranking of characteristics. Quality/price ratio and delivery reliability were indicated as much more important than the remainder of the top 8. Reciprocity and personal benefits to the buyer were grouped far last. The five characteristics ranked most important are shown in Table 3.

The results of the study show once more that the PDS element delivery reliability is an important determinant of vendor selection.

Dickson (1966) studied the factors that should be considered when selecting a vendor, how the product type influences the decision, and how to weight the relative importance of each factor across product types. A mail questionnaire was sent to a random sample of 300 members of the National Association of Purchasing Agents. Questionnaire sections covered information on the respondent's firm, the firm's vendor selection practices and procedures, and the respondent's decision behavior in the selection of vendors based on hypothetical case situations. The 170 responses represented 67.8 percent manufacturing firms, with the reminder from service and other non-manufacturering firms. A range of firm size in sales and employees was represented in the sample with roughly 20 percent small, 60 percent intermediate, and 20 percent large. The median respondent firm had 794 employees and 4 buyers.

In the decision behavior section the respondent was asked to read a hypothetical case situation, put himself in the position of the purchasing agent, and rate the importance of 23 purchasing factors from 0 to 4, with 0 representing no importance, 1 slight, 2 average, 3 considerable, and 4 extreme. The cases were as follows:

> Case A - a large industrial chemical company needs to purchase 10 barrels of paint to be used on walls which are subject to severe fumes.
>
> Case B - a large university has a need for 200 additional desks for a new faculty office building.
>
> Case C - a very large aerospace company is building an orbital laboratory and requires two specialized computer controlled stabilizing systems to be delivered in two years.
>
> Case D - a large aerospace company has an immediate need for artwork, make-up and printing services for a 2500 page training manual with 2000 illustrations.

Aggregate rating of the top 5 factors over all four cases are in Table 3. The ranking of the 23 factors did vary by individual case situation but quality, delivery and past performance were always in the top 5. Analysis of variation in the factor rating showed that there was general agreement on very important and not important factors, but there was not agreement on the ranking of factors between these two extremes.

For this dissertation the contribution of Dickson is the identification of delivery and performance (which are both PDS elements) to be important across product and purchasing situations.

Discussion of the Integrative Review

The results of Table 1 suggest that across multiple products and industries, physical distribution remains an important element in supplier evaluation, customer perception, and customer satisfaction. It would be tempting to make a definite statement as to exactly how important PDS is in relation to the other factors impacting the buyer, but it is much more reasonable (considering the studies used and method used to integrate) to just state that there is an indication that PDS and price/quality stand out as major factors.

Mentzer, Gomes, and Krapfel (1989) agree with the results in Table 2, that is, the major elements of PDS are availability, timeliness, and accuracy in filling orders. Thus, the integrative review has indicated the critical indicators of the PDS construct which the simulation model must generate. This will be discussed in detail in the Methodological section which follows later.

COMPUTER SIMULATION AND DECISION SUPPORT SYSTEMS

In order to investigate the effects of Just-in-Time (Kanban) systems on key PDS elements and on a complex channel system's profit performance, it will be necessary to have such a system available for manipulation. Such manipulation of an actual operating physical distribution system would not be realistic.

To actually introduce the physical distribution alternatives under study in an organization and to induce the environmental conditions of concern would most often not be practical in terms of time, cost, legality, organizational impact, and customer impact. Also, if the researcher wished to view the system response over an extended period, the project would likely take an unreasonable amount of time to complete. The cost of such actual changes to distribution systems would likely be prohibitive and there would not be sufficient incentive for the firm to operate under non-cost-effective alternatives just to gain knowledge. Under current regulation some alternatives may be illegal or restricted by channel or labor contracts. Even if it were possible to make these changes or to control environmental conditions, the probable negative impact on the organization and its customers would be prohibitive. Customers would seek other sources of supply when inferior treatments were applied and would be unlikely to return for other treatments. Manipulation of a computer simulation of a distribution system has the advantages of time compression, cost effectiveness, experimental control and ease of replication (Fishman 1978).

Thus, a mathematical representation of a channel system operation is suggested. There is considerable precedent in the literature for the utilization of a multi-echelon, stochastic, dynamic, simulation model to represent a physical distribution channel (Bowersox 1972, Forrester 1961, Gross and Soriano 1969, Geoffrion 1976, House and Karrenbauer 1978, Speh and Wagenheim 1978, Bowersox, Closs, Mentzer, and Sims 1981, Mentzer and Schuster 1982).

The computer model to be utilized in this study is a multi-echelon, stochastic, dynamic simulator, termed the Global Planning Model (GPM). The system is intended as a strategic decision support system (DSS) which can be used to test the effects of varied conditions of market and company operation on a domestic or international basis.

Sprague and Carlson (1982) characterized a decision support system as an interactive computer based system that "helps" decision makers utilize data and models to solve unstructured problems. "Helps" is a key word because unlike optimizing programs, decision support systems leave the decision to the manager. The system provides interactive capability to access and manipulate data and quickly check the results of a variety of alternative conditions.

GPM has the ability to accept initial information on channel configuration and operation and generate a decision support system to reflect the stated conditions (including demand and physical supply conditions and uncertainty). Since GPM can reconfigure the specific DSS to be used, it meets the requirements of a "DSS generator", and, in fact, can be used to represent the distribution systems of a variety of organizational structures. As a typical DSS, GPM operates with a data base (historical operating results of the actual or hypothetical company in question), a model base (in this case, a simulation of company operation) and a software system (which provides the dialog subsystem) which allows the user to access and integrate the model and data bases.

Models of this type can be called multi-echelon when they represent a number of consecutive levels in the distribution channel. That is, they simulate product flow from manufacturing plants through consecutive channel members to the final customers' locations (Bowersox 1972).

A dynamic event driven model, such as GPM, operates over time allowing factors like demand characteristics to act on performance measures, (this is as opposed to a model which is static in time, such as a plant location optimizer). Clearly, conditions that maximize performance at a static point in time, may not be the right conditions to optimize performance over time.

A model is termed stochastic if it contains randomly generated variables. In this case factors such as demand and transit time are chosen from their own unique probability distributions to represent variability in the real world environment. House and Karrenbauer (1978) state that "it has been shown that the variance of transit time impacts the average inventory level more severely than does the average transit time." Thus, average values often do not adequately represent the real world random behavior which impacts system performance and a stochastic representation is necessary.

A simulation model with all the above characteristics would contain the following components:

System state -	the collection of state variables necessary to describe the system at a particular time.
Simulation clock -	a variable giving the current value of simulated time.
Event list -	a list containing the next time each type of event will occur.
Initialization routine -	a subroutine used to initialize the model at time zero.

Timing routine - a subroutine which determines the next event from the event list and advances the simulation clock to the time when the event is to occur.

Event routine - a subroutine which updates the system state when an event occurs.

Main program - a subprogram which calls the timing routine to determine the next event and then transfers control to the event routine.

Statistical counters - variables used to store statistical information about system performance.

Report generator - a subroutine which computes estimates (from the statistical counters) of the desired measures of performance and prints a report when the simulation ends (Law and Kelton 1982).

The GPM simulator will thus represent operations day-by-day, event-by-event, between the sources of supply, distribution centers, branch warehouses and customers. Orders are generated and filled, branch inventories are depleted and must be replenished from distribution centers which similarly must order from their sources of supply. If there is insufficient material on hand, the order is back ordered or, if possible, transferred to another filling location. Capacity limits may be exceeded and storage expansion required. In general, the model elements incur costs and earn profits in much the same manner as a real world operation as traced by its operations tracking or financial system. In fact, the model is validated in part by successfully showing that the model generates financial reports equivalent to those historically generated by the company in operation. Adapting this model for the typical effects of

Just-in-Time procedures (under varied conditions) will produce data which can then be analyzed to establish relevant relationships.

The investigation will involve a distribution system where JIT effects will be represented by several adjustments including replacing the economic order quantity and reorder point calculation with a Kanban type small lot request to replenish only the amount processed. The model will simulate a temporal span of company operation (the length of which will be determined by the pilot study) with measures of PDS level and system performance reported quarterly.

CHAPTER III

METHODOLOGICAL APPROACH OF PAST RESEARCH AND THE PROPOSED STUDY

METHODOLOGICAL APPROACH OF PAST RESEARCH

The evaluation of a Just-in-Time (JIT) system is a specific example of a distribution planning problem. Geoffrion (1975) defined distribution planning (as used in this context), as the "planning of the principal configuration and flow aspects of distribution system design, involving either modifications to an existing distribution system or the design of a new one." Geoffrion suggested that the following are typical of questions that have to be resolved simultaneously (since they are interactive) suggesting a "systems" approach:

(1) What is the optimum number and location of warehouses and distribution centers?

(2) What is the optimum size and product inventory of warehouses and distribution centers?

(3) Which customers should be serviced from which locations?

(4) What should be the annual transportation flows throughout the system?

(5) What is the trade-off between customer service level and cost?

To perform this type of analysis, the effects of cost savings in some areas must be compared to possible cost increases in other areas. These areas include: warehousing (and distribution center) operation and inventory carrying costs, costs to expand or reduce warehouse capacity, and costs of transportation between plants, warehouses and customers.

The mathematical requirements for analyzing the options of even a simple distribution system can be considerable. Computer-assisted methods for distribution system planning are necessary and several approaches have been available for many years (Geoffrion 1976). The three basic roles which the computer may play in such planning are:

(1) preparing and forecasting forward large amounts of historical data (costs, demands, ...).

(2) Evaluating particular candidate plans in terms of cost (effects on finance, transportation, manufacturing, marketing,....) and other quantifiable characteristics such as customer service levels.

(3) Finding the "Best Plan" in light of the given environmental scenario (Geoffrion 1976).

The principal available methodological approaches to computer-assisted distribution systems planning include:

(1) General Mixed Integer Linear Programming.

(2) Optimizing methods for a single stage (often single product) of distribution.

(3) Software packages for simple (limited configuration) distribution systems.

(4) Heuristic methods.

(5) Computer simulation.

Geoffrion's (1975) review of these available methods compared their usefulness for different applications. He concluded that computer simulation "is best for evaluating a few fully specified distribution design alternatives in great detail as regards their dynamic operating characteristics." The application of JIT system alternatives will be such a group of fully specified design alternatives which will be investigated in detail while in dynamic operation.

Similar earlier typologies of methodological approaches to distribution planning were suggested by:

(1) Ballou (1973)
- single facility location models
- multiple facility location models
    - Algorithmic models
    - Mathematical Programming Models
    - Heuristic Models
    - Simulation Models
    - Dynamic Location Models

(2) Bowersox (1978)
- symbolic
    - comparative analysis
    - break-even analysis
    - flow charting
- Analytic Techniques
    - gravity location
    - linear programming
        - transportation
        - simplex
        - mixed integer
        - separable
        - trans-shipment
        - decomposition
        - variable-range
- simulation techniques
    - static
    - dynamic

Karrenbauer (1980), suggested that such system modeling approaches can be generally categorized as: (1) optimization models, (2) heuristic models, and (3) simulation models. A selective literature review of research utilizing these three general categories of models will reveal their individual characteristics. These characteristics can be compared to the specific objectives of the present investigation to select the appropriate approach.

The modeling objectives of the present investigation are:

(1) to accurately represent a distribution system as it would function under actual operating conditions.

(2) to measure the effects of the adoption of JIT systems in the presence of various levels of materials management operational and demand uncertainty.

(3) to complete the investigation given equipment, time and resource constraints.

To meet objective (1), the model must be flexible, dynamic, adaptive, and valid. In this usage "flexible" refers to the model's ability to represent various scenarios of operating conditions (different channel configurations and operating procedures, including JIT). The "dynamic" requirement refers to a model which represents a system as it evolves over time (in this case many periods of daily operation). A dynamic model uses the output of one time period as input to the next period. This is as opposed to a "static" model which represents a system at a particular point in time. The "adaptive" requirement refers to the fact that change occurs within actual distribution systems in response to changed operating situations. A realistic model must be capable of making these procedural adjustments, (e.g., changing inventory policy in the face of demand variation, expanding warehouse capacity, dealing with supply interruptions). Further, it will be necessary to be able to redefine the system state variables at a countable number or points in time, (that is, any time events occur which may change the system state). Such discrete models often use consecutive days as the time units at which events occur (orders are received, inventory ordered, shipments sent out,...) and system values are re-evaluated (total costs, inventory totals, warehouse expansions,...). The "valid" requirement refers to the model's generation of quantifiable measures which can be validated statistically and validated by comparison to historical actual operating data.

To meet objective (2) the model must represent all the major distribution components which affect costs and procedures; be multi-product, multi-echelon, and multi-facility capable; and be capable of stochastic demand and stochastic lead times. The major distribution components must be represented for the model to reflect reality. When events occur and states change, it must be reflected in time and cost. When customer orders come in, they represent time and cost, as do transportation, carrying of inventory, warehousing, and material handling.

The JIT effects of research interest may vary over product lines. Different products have different costs and lead times associated with them. Treatments may affect a high cost product (or perhaps a long lead time product) differently than they affect a low cost product (or perhaps a short lead time product). JIT effects may also vary over multi-echelon distribution levels (producer/source of supply, distribution center/warehouse, branch, and customer) which all have different relationships with the variables manipulated in the treatments. JIT effects may also vary with uncertainty in physical supply (materials management system operation) and demand (customer requirements). Thus, the model must have the capacity to represent physical supply and demand as random variables each with its own probability distribution. This capability would cause the model to be termed stochastic; as opposed to a model without random variables which would be termed deterministic (Law and Kelton 1982).

To meet the third objective the model must be available, run in a reasonably efficient manner, and utilize computer equipment which is available to the researcher.

Given these objectives it is possible to review the distribution planning literature to evaluate available methodological approaches in comparison to this study's research objectives. Since the objectives defined will disallow many types of approaches, it should be useful to group approaches broadly in the manner suggested by Karrenbauer (1980). That is, it will be useful to review examples and characteristics of models which (1) utilize heuristics, (2) optimize, and (3) simulate.

Thus, the available research methodologies in distribution system modeling will be critiqued in two steps. First, the three general categories of models will be evaluated by consideration of the model concept, representative models, and comments on how well each meets the requirements previously stated for JIT research. Once the most suitable model category is identified, the second step will be to critique in detail the methodology of past studies which used that model approach.

The objective of this review is to consider the strengths and weaknesses of past methodology before determining the specific research design for the present JIT study. To critique the past methodologies, consideration will be given to the concepts of external validity, construct validity, internal validity, and conclusion validity (Judd and

Kenny 1982). In a simulation experiment the meaning of these terms may vary somewhat from their use in social science research. For example, no single simulation of an organization would claim to produce externally valid results (the extent that the results can be generalized to other populations and settings). The pertinent question is whether the model adequately represents the category of organization it is intended to represent. Is there accuracy in the simulation? Statistical system validation methods (discussed in detail later) have been developed to establish that the model does respond as the actual system it represents. Without this system validation, consideration of other validities has little meaning.

Judd and Kenny (1982) suggested that since external validity (the ability to generalize from samples to populations) and construct validity (the extent that indicators represent the construct of interest) are both concerned with the ability to go from specific operationalizations to theoretical phenomena of interest, it makes sense to collapse them into a single issue.

The third validity concept, internal validity, is generally defined as the extent to which the observed effect is caused by the treatment rather than rival causes. In a mathematical simulation this often has little meaning since control of other factors is assumed complete (if the model is properly specified). There may be complex interactions that cloud the understanding or interpretation of why or how the treatment causes the results, but it is only the treatment that varies, so to that extent it is causal.

The last issue is conclusion validity (the extent to which statistical conclusions are accurate), that is, the extent that the methodology has the precision and power to detect the relationship, and the extent that the statistical assumptions of the methods have been considered and met (Judd and Kenny 1982). Analysis of the correctness of the statistical assumptions of the data are rarely made in computer simulation and this will be a concern throughout all the models discussed.

All of these issues will be used in the evaluation of candidate methodologies for the JIT study.

HEURISTIC MODELS

Model Concept

The complexity, difficulty and volume of calculations required to "solve" a realistic distribution planning scenario has led to the use of a variety of simplification approaches. Heuristic approaches, which have been extensively used to simplify manual calculations, can also be incorporated into computer system analysis programs. Often, if such simplification approaches are not already in manual use, the system analyst (modeler) can develop some rules of thumb or "heuristics" which substantially reduce the number of alternatives that need to be examined and sorted through.

Representative Model - Kuehn and Hamburger

In the early 1960's Kuehn and Hamburger (1963) introduced one of the first comprehensive heuristic-based models of a distribution system. The objective of the model was warehouse location for cost minimization. Important capabilities of the model include use of (1) multiple products, (2) fixed and variable warehousing costs, (3) warehouse capacity limits, (4) source of supply capacity limits, (5) effect of delivery time on customer service, and (6) actual transportation rates.

The heuristics used include: (1) geographical locations for warehouses should be near concentrations of demand, (2) near optimum results can be obtained by locating warehouses one at a time and adding the one warehouse that produces the greatest cost savings for the system, and (3) only a small subset of all possible locations needs to be analyzed to determine the next warehouse to be added.

While such a multi-product, multi-facility, multi-echelon model was an important advance, its structure was intended for warehouse location and does not have dynamic nor stochastic capability. Nor does it represent all the operational detail of the distribution system elements.

There are heuristic elements (simplification and approximation) in all computer models (Geoffrion 1975), but ruling out large categories of solutions does not seem justified when dealing with complex systems. Interactions of system elements can produce counter intuitive optimal solutions which may be disallowed by simplifying heuristics. As noted by Geoffrion (1975) (due to advances in computer programming and hardware) "the best of today's optimizing methods are actually faster than many available heuristic methods for the same model." He further suggested that heuristic models are more suited to the repetitive tasks of production scheduling or vehicle routing (where good solutions on average may suffice), rather than critical requirements of strategic planning.

OPTIMIZATION MODELS

Model Concept

Heskett, Glaskowsky, and Ivie (1973) described optimization techniques as those which provide the "one best answer." This optimum solution is often found in terms of minimization of a cost objective function or the maximization of a profit objective function in the presence of some given operating constraints. In a similar statement, Bowersox (1978) suggested that optimization techniques such as center-of-gravity and linear programming isolate a precise mathematical optimal solution.

Often these techniques are based on restrictive assumptions such as; single point demand, linear transportation costs with distance, straight line routing, static system representation, and single product consideration (Ballou 1973).

Representative Model - Geoffrion and Graves (1974)

This approach utilizes a complex form of mixed integer linear programming. Looking at the model very simplistically, it is suggested that one should visualize a master problem and a set of transportation flow subproblems for each product. The master problem considers distribution center costs, capacities and operating restrictions. The transportation subproblems consider production costs, transportation costs, production constraints, and customer demand. "Each iteration of the master problem produces an improving lower bound on the theoretical optimum, while each iteration of the transportation subproblems establishes a usually improved upper bound" (Karrenbauer 1980). When the results converge the optimum solution is reached.

While the model is certainly one of the most advanced optimization models available for distribution planning, it is static, deterministic, and does not consider total system effects. This approach is therefore also unsuited to the investigation of JIT.

SIMULATION MODELS

Model Concept

Some real-world system problems do not lend themselves to solution by optimizing algorithms. To mathematically "solve" a problem within a complicated business system model, the model must represent all of the interacting elements and their relationships. This implies that the behavior of the total system is known. In real world business situations this is rarely the case. An example of this approach is traditional econometric models which represent systems by sets of linear regression equations. In real world systems it is the behavior of individual components which is known rather than the behavior of the entire system (Kleijnen 1974). The knowledge of these individual behaviors can be made to interact in a simulation, but they cannot be solved with a mathematical optimizing process.

In distribution planning one approach to a simulation model would involve a mathematical representation of the detailed functioning of a company's complete distribution system. The elements of the mathematical model distribution system operate on paper much the same as their real world counterparts. For example, customer orders are received, time passes while they are processed, inventory is depleted and must be recorded, labor costs are incurred, sources of supply shut down, some orders are back ordered, and some shipments are returned from the customer. These are just a few of the real-world distribution system elements that can be represented in a simulation model. Rather than arriving at an optimal answer, the model produces results much like an actual distribution system, (profit or loss, physical distribution service levels, percent stockouts, percent trans-shipped, inventory levels and costs,...). Under a given set of operating conditions, simulated years of operation can be compressed into a short period. Thus, the effect of distribution policy changes on the entire interdependent system can be observed over time. Often the objective is to compare results under various sets of operating conditions. Because simulation is only a synthetic representation, it permits the testing of various schemes for developing better distribution methods and achieving lower operating costs, leading ultimately to a plan of distribution at lowest cost for a given set of performance goals (Shycon and Maffei 1960).

The simulation process is illustrated in Figure 2. It is this specific process which will be discussed item by item for application to the study of JIT.

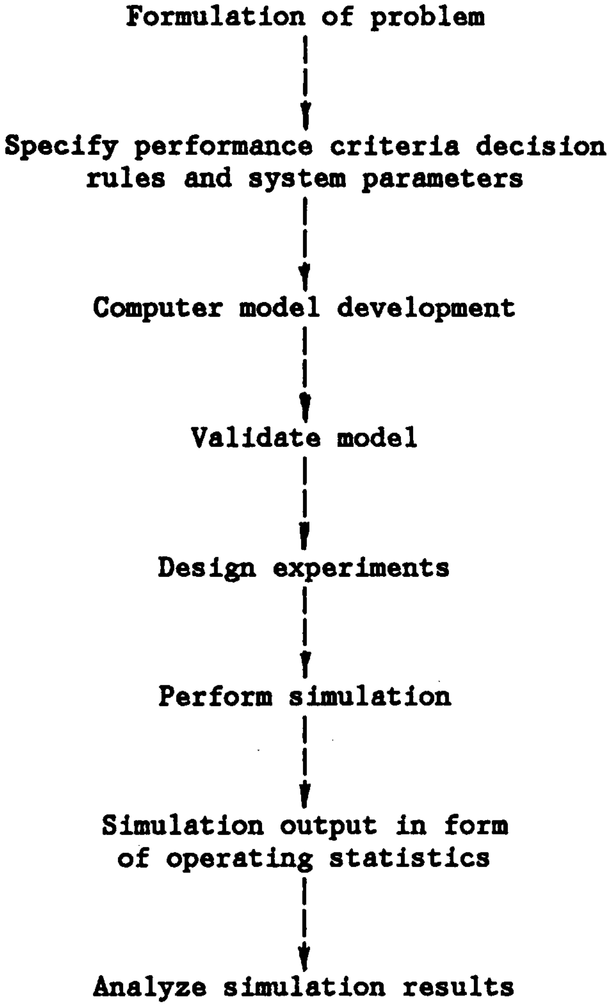
Representative Models

Since the introduction of computer modeling, a great number of models have been utilized. The experimental design, strengths and weaknesses of several will be reviewed here. Significant results will be noted as a basis for future hypothesis generation in the Just-in-Time research.

Forrester Model. Forrester (1961) developed one of the first large scale production distribution models of the firm for experimental use. To investigate system response he introduced the following:

(1) a demand increase of 10 percent
(2) a 10 percent rise and fall in sales over one year
(3) an irregular sales pattern
(4) a reduction in available clerical days.

Forrester's output was graphical without statistical analysis, but his results form the basis for visualizing system response to demand variation and uncertainty. In experiment (1) above, January orders from customers to retailers were increased by 10 percent. By March, retailers (as represented by a function in the model) over responded in their orders to distributors by increasing their orders by 16 percent. By April, distributors orders peaked at a 28 percent increase, and by May factory production peaked at a 40 percent increase. After the peaks, cutbacks followed as inventories were worked off. Rather than the actual per-



Adapted from
Lee, Moore, and Taylor (1981)

THE SIMULATION PROCESS

Figure 2

centages, the key finding of the study is the visualization of the significant system waves which were generated by a modest increase in a demand input. Even more significant fluctuations follow the rise and fall of (2) and (3)'s irregular sales. This type of research led to investigations by others of the effects of uncertainty of demand and lead time on system performance. The JIT study (measuring the effect of JIT in the presence of uncertainty) will be an extension of the stream of research resulting from Forrester's seminal study.

Forrester (1958) stated that "to determine the behavior of a system by simulating the performance of its parts requires that one describe exactly, and in detail, the characteristics (relationships) which are to be included. The validity of the outcome of the system studies depends on the judgment of what is pertinent to include in the system description." Forrester's model included mathematical representations of "some forty relationships" involving factors such as; inventory levels, orders, shipments, purchasing rates, mailing delays, transportation times, and factory lead times.

To model a dynamic multi-echelon distribution system requires much more than forty relationships. A gross simplification of the real world relationships would be likely to produce results which have little internal validity, due to the great possibility of rival cause effects inherent in a poorly defined model.

Forrester considerd each independent variable in turn with all others held constant. Without any notation of sample size and without statistical tests of the significance of the results, statistical conclusion validity (that is the extent that statistical conclusions are true) is non-existent. As mentioned earlier, no one simulation is going to claim external validity (that is, how generalizable the results are to and across other subjects settings and situations).

The notation of these weaknesses is not a criticism of Forrester's pioneering work. In fact, the considerable interest in the simulation which was generated led to future methodological improvements in the simulation approach.

Bonini Model. Although not a distribution system investigation, Bonini's (1963) simulation of the behavioral theory of the firm laid the groundwork for experimental design and statistical analysis in simulation experiments. Eight factors were chosen with two values each, reflecting various organizational, informational, and environmental conditions that could affect the firm's decision making process. With a full factorial design $2^8 = 256$ computer runs would be required. By assuming that interactions higher than first order were zero and that standard statistical assumptions were met, the design was reduced to a fractional factorial design requiring only 64 computer runs. Thus, the main effects and first order interactions could be estimated while still blocking the effects of different starting conditions. The response variables included price, inventory level, cost, sales, and profit, each as measured by mean, standard deviation, and trend (each response variable was run as a single experiment). Standard Analysis of Variance (F-test) was used to determine if changes in the independent variables resulted in significant variations in the response variables.

Bonini's experimental design and methodology are well suited to simulation research, except that lack of model (system) validation leaves all conclusion validity in question.

Ballou Model. Ballou (1976) investigated the effect of changing time lags in a physical distribution system. Each simulation run was made with a set mean and standard deviation assigned to each of the time delay elements, (order transmission, order preparation, delivery to warehouse, shipment to customer, ...). With a series of experiments, the sensitivity of system performance (total cost, stockout rate, stock level record accuracy and forecast accuracy) versus changes in time delays could be found. Time delays were generated with normal distributions using Monte Carlo methods. Ballou's results were interpreted as follows:

1. Shortening order transmittal delay may increase costs and lower system performance. System control values like reorder points and economic order quantity have been set according to historical time lags. Changes in the lags upset the system and can create problems like excessive inventory until the system is retuned.
2. System cost and performance are more sensitive to time delay changes in order transmission, processing and computer update time than they are to stock order transmission or order receipt transmission times.

Ballou's model is multi-echelon, dynamic and multi-product (in that it was run with five typical products). The approach used is suitable for JIT investigation with the necessary modification of the Monte Carlo (fixed per run) time lags and the lengthening of the time horizon.

As mentioned earlier, in a simulation study questions of internal and external validity are very dependent on the model (system) validation of the computer simulation itself. How well it reflects the actual response of the real world system is basic to the question of "are you measuring what you think you are measuring," and do the numbers mean anything? Rather than problems created by some unknown rival cause or faulty indicator of the construct, the concern here is that the model's response can be a meaningless mathematical response from some function or interaction in the model.

Validation of the Ballou model would be difficult since it was a simplification of the true system in three major areas:

(1) The company's computerized inventory control system was taken as the surrogate for the entire physical distribution system. It would be preferred from the systems approach to have a model which responds as the entire corporation or channel rather than one distribution system element.

(2) For the purposes of his study Ballou shut off two important features of the real world inventory control system which he postulated would distort or mollify the effect of the treatments: (a) the minimum level inventory control which would prevent stockouts and (b) the maximum level control which would prevent small orders. If research is looking for the effects of treatments on systems, it does not seem reasonable to render the system's self-correcting or self-limiting aspects nonfunctional. Many results in this line of research indicate significant results with the statement that system operating controls would have to be retuned. In reality, the real world system has the capability to retune itself if allowed to. For example, in a real system, managers would not passively sit by and watch unsold inventory accumulate even beyond the capacity of warehouses, or lead times extend far beyond the point where customers would stop doing business with the company. Action would be taken to correct the problem. The data output of computer models that do not respond with

real world controls, self corrections, and limitations have limited internal and external validity as these issues were defined earlier.

(3) The inventory control model was taken from a company with over seven hundred products and 70,000 customers. It would seem reasonable that there would normally exist some competition for limited resources among the products. The Ballou study used just five products which would seem to imply very limited product interaction and virtually unlimited capacity and resources.

The Long Range Environmental Planning Simulation (LREPS) Model. In the late sixties, Bowersox and a team of graduate students at Michigan State University developed LREPS, a comprehensive and flexible distribution simulator, which has been applied to a variety of companies and situations (Bowersox et al. 1972; Karrenbauer 1980). "In many ways (it was) a significant milestone in the historical development of logistic system models. For the first time, a truly large-scale event-driven, dynamic (stochastic) temporally integrated analysis tool was available to probe the complex often subtle intricacies of alternative system operating policies" (Karrenbauer 1980).

The LREPS model perhaps comes closest of all to meeting the requirements previously mentioned for the JIT study. However, beyond the intrinsic shortcomings of all simulation models, Bowersox (1972) noted that limitations of LREPS included (1) a large amount of data is required to initialize, (2) improved data preparation procedures are needed and (3) the complexity of LREPS makes it unsuited for many smaller scale studies.

Speh and Wagenheim (1978) suggested that to manage a distribution system effectively, an executive must recognize the presence of uncertainty and evaluate its impact upon planned operations. In their research with the LREPS model, demand and lead time uncertainties were represented by three measures; the shape of the probability distribution, the average level per time period, and the variance around the average value. The LREPS model was configured with three echelons (one manufacturer, to two wholesalers, to four retailers each). Each simulation run involved one combination of the three experimental factors for a total of sixty at 90 days and sixty at 120 days. As demand was varied, lead time was held constant, similarly, as lead time varied demand was held constant. Four control runs were made with both demand and lead time constant as a basis for system performance under certainty. The independent variables were combinations of demand and lead time factors from the following set:

Demand distribution - normal, lognormal, poisson, negative binomial, gamma, exponential.

Leadtime distribution - normal, lognormal, poisson, gamma, exponential, erlang.

Demand variance - coefficient of variation (VARX/XBAR) = .10, .30, and .50 (except for poisson and exponential).

Lead time variance - coefficient of variation = .18 and .375 (except for poisson, exponential and erlang).

Demand average - 75 and 25 units per day.

Lead time average - 4 and 7 days.

A full factorial design was used to observe the effect of the experimental variable over the full spectrum of conditions, (if a single factor experiment had been used, all other factors would have been held constant which could limit realistic responses).

The response variables output on each simulation run included measures of:

System cost -	total per unit system cost. - per unit activity center costs (transportation, inventory, facility and handling).
Service -	percent total demand stocked out at the retail level.

Data analysis consisted of analysis of variance using the f-test (do means differ), Tukey's test of multiple comparisons (how do they differ), and Dunnett's method of multiple comparisons (how do they differ with a control mean).

Uncertainty produced reduced service in both cases with lead time uncertainty having the greater impact. As the shape of the distribution became more skewed, service was also reduced. As the coefficient of variation increased, service decreased.

The presence of high demand uncertainty did not significantly increase total system cost, while high lead time uncertainty did. The individual uncertainty factors varied in their cost effect. Results are summarized as follows:

Factor	Significant	Not Significant
Demand pattern		*
Lead time pattern	*	*
Demand variance		*
Lead time variance	*	
Demand level	*	
Lead time level	*	

The research supports the belief that consistency is more important than speed. The strongest effect is from lead-time variations which increase cost and reduce service.

This relatively recent study shows considerable advancement in experimental design and methodology. Verbal consideration was given to meeting the statistical assumptions of analysis of variance and model validation (although neither was checked). The authors suggest that model validation is implicit since the "LREPS" simulation model has been validated with a wide variety of empirical data. They also argued that the real world application is evidenced by the fact that the model has been effectively applied by over 15 corporations.

That this is not meaningful proof of model validation can be seen from Bowersox et al. (1972) original LREPS validation procedure, which was stated as:

> (1) determine if the time series of the endogenous variables is statistically under control,
>
> (2) compare the model output to actual historical data, and
>
> (3) examine the sensitivity of model assumptions.

Bowersox et al. (1972) went on to state that various validation methods showed contradictory findings. "The only conclusion that can be drawn is that the validity of the model's (LREPS) predictive capability has not been established" (Bowersox et al. 1972). Even if this validation had been successful, it would not be sufficient for future studies. Just as a questionnaire used in previous research must be pretested again before use in another application, simulation models cannot rely on past validations in other applications.

A rather serious problem was created by the authors using only one observation per cell. With only one degree of freedom for the difference between means test, the statistical conclusion validity was low. Within cell variances could not be computed to estimate measurement error due to the stochastic workings of the model. Cell by cell comparisons and tests for interactions between factors were therefore compromised.

The Karrenbauer Model. The Karrenbauer (1980) simulation model was designed to represent discrete transactional events of the "ongoing day by day" policies and procedures of a corporate logistics system. The model is dynamic and stochastic and contains elaborate feedback loops to make it reactive. The echelons represented by the model are limited to producing plant, distribution center, and customer. The model was used to conduct two experiments, the first concerned the effect of alternative communication system technologies, and the second concerned alternative replenishment shipping planning strategies. Since the same methodology was used, this review will emphasize the first experiment only.

Karrenbauer chose a complete two factor design with replications. This insured that formal statistical tests could be performed for primary and interaction effects. The experiment for each cell was replicated five times which allowed computation of with-in cell variances to establish measurement error attributable to stochastic processes in the model (an important factor not considered in previously mentioned models). In each case the model was run for one simulated year.

The two independent variable factors were:

(1) type of internal communication system (three levels-pure mail, mixed mail and electro-mechanical, and pure on-line).

(2) target inventory in stock rates maintained across all products (three range levels - [98-99percent], [95-96percent], and [91-93percent]). (Due to the stochastic demand and lead time, it was necessary to specify a range of in-stock rates).

The two factor design with 3 levels each results in nine cells, and analysis was completely repeated for each of the six dependent variables which measure system performance. The dependent variables used were: (1) net revenue, (2) cost/unit sold, (3) transportation cost/unit sold, (4) average daily inventory, (5) customer order cycle time, and (6) demand weighted customer order cycle time.

Analysis of variance tables were produced with the General Linear Models procedure within SAS. Traditional sums of squares breakdown and F-test using a significance level of alpha = .05 and Duncan's multiple range test were used on the levels of both factors to establish grouping of the cell row and column means (i.e., groups of cell means that were not significantly different from one another).

Across the cost performance dependent variables the all-mail system performed poorly (with poor performance indicated by increased cost relative to the other systems investigated). Interestingly, the on-line technology did not outperform the mixed system. Faster was not necessarily better.

As expected, system costs, inventory levels, and customer order cycle times were related directly to the in-stock rate levels. An unexpected dysfunctional interaction effect did take place for the cost dependent variables. This suggests that modification of a factor like increasing information flow speed may require retuning of system operating procedures (e.g. decreasing inventory in-stock rate or reorder point shipment dispatch triggers).

Karrenbauer (1980) utilized a systematic model validation procedure which was an improvement over previously mentioned studies. He also recognized that "substantial controversy still exists with respect to the proper means by which simulation models and statistical testing procedures can be joined in a valid experimental design." He also acknowledged that it could not be established that the statistical assumptions of analysis of variance were met, but the method was nevertheless useful because: "(1) it has evidenced statistical robustness even in light of assumption violations, (2) there existed wide familiarity with, and acceptance of the procedure; and (3) other alternatives were judged to be less satisfactory" (Karrenbauer 1980).

Karrenbauer's design, control, and statistical analysis seem to be superior to much of the previous literature in terms of the internal, external, and conclusion validity issues previously mentioned.

OTHER MODELS

Two important approaches in simulation that are not judged suitable for this particular JIT study should nevertheless be mentioned (because their results do impact the hypotheses to be developed).

Rogers (1979) examined the profit generating potential of customer service with response surface methodology. That is, profit responses were used to construct a response surface model of the customer service/profit relationship. Rogers' most significant finding was that the sensitivity of profit to customer service variables can be determined.

Another study, Huang, Rees, and Taylor (1984) used the Q-Gert simulation language to simulate a multiline, multistage production system which utilized a Kanban control process. It was desired to estimate the effects of variability in processing times, bottlenecks and demand rates. Each was approached with a separate experiment with the response variables of overtime, inventory, and production units reported in terms of mean and standard deviation. Important results include: (a) success of JIT requires reducing processing time variation, and (b) large fluctuations in demand render the JIT system impractical.

Both the Rogers and Huang, Rees, and Taylor approaches, although important, do not provide the type of model judged necessary for the present JIT research.

PROPOSED SIMULATION STUDY

After establishing the importance of the Just-in-Time issue and reviewing the methodology of past research, it is left for this section to describe and justify the approach to be taken in this particular study.

Due to stochastic elements and the complex system-wide effects of JIT, it would not be practical to expect to experiment with real-world systems, nor would it be practical to seek optimal analytical solutions. In this situation, simulation may be the only type of investigation possible (Law and Kelton 1982). Since a simulation approach is suggested, the process described previously in Figure 2 will be followed.

PROBLEM FORMULATION

According to Lee, Moore, and Taylor (1981) (Figure 2), the first step in simulation research is problem formulation. Since limited research results are available on the subject of JIT, this study's objective will be to explore the effects of several alternative JIT systems, each under high and low demand uncertainty and high and low materials management operational uncertainty. High demand uncertainty is defined here as a greater relative variance in the incoming customer order stream as compared to the low demand uncertainty condition. High materials management operational uncertainty is defined as a greater relative variance in the order cycle time of incoming materials from sources of supply as compared to the low materials management operational uncertainty condition. The alternative JIT systems will be designated as follows:

(1) Materials Management JIT - JIT applied to the flow of material from the supplier to the focal organization and to material flow within the focal organization.

(2) Physical Distribution JIT - JIT applied to the flow of material from the focal organization to the demand points (customers).

(3) System-wide JIT - JIT applied to both (1) and (2) above.

(4) Non-JIT System - A channel relationship that does not utilize JIT techniques (conventional higher quantity less frequent orders, EOQ purchasing, and higher inventory levels).

These terms are defined in greater depth in a subsequent section which discusses the channel configuration represented in Figure 5.

RESEARCH PROPOSITIONS

So far in this study reviews of literature have provided a conceptual base (GST), independent variables (JIT configuration, uncertainty), and dependent variables (PDS). These concepts can now be used to address the the research questions of Chapter I. While the JIT investigation will be exploratory in nature, the research topic does lend itself to hypotheses testing. The hypotheses proposed will be based on the proposition that JIT should lead to reduced costs and improved profit performance. Since many Japanese companies have set up JIT manufacturing in the U.S., the environment here must not restrict its practicality.

A second proposition is that a system with JIT on the materials management and physical distribution sides (JIT system-wide) will not be negatively impacted by uncertainty in demand. This ability to handle uncertainty does not extend to materials management operational uncertainty. If the system is responsive, materials management operational uncertainty will be met with increased inventory to maintain sales and PDS level. This will increase costs and reduce profit. Demand uncertainty on the other hand will be passed up the channel. Highly variable orders from the customer will mean highly variable orders to the distribution centers and back to the sources of supply. Under a low inventory JIT system, unless some performance limitation does not allow a unit along the channel to respond, much of the demand uncertainty will pass up to the source of supply.

Huang, Rees, and Taylor (1983) found that JIT can not function efficiently in the presence of demand uncertainty. On the surface this would seem to refute the second proposition. But as just indicated, the definition of unit capabilities is critical. The Q-GERT simulation language model used in the Huang, Rees and Taylor study did not reflect the true capability of a "Toyota" type JIT system to respond to demand variations as described by Monden (1983,1984). That is not to suggest that their findings were incorrect. Their results were accurate for JIT applied to a fixed capacity system. A major contribution of the Huang, Rees, and Taylor study is due to the fact that the system model they used closely resembles a typical American production set-up with Kanban added. The typical American production set-up is not able to increase and decrease cycle time in the manner of the "Toyota" system described by Monden (1983). The "Toyota" system basis for this capability is called "meeting demand through flexibility" and consists of changing the allocations of interchangeable workers to operations. Under normal demand a worker may perform two sequential balanced time operations. When unexpected high demand occurs another worker is given the second operation, thus output is doubled. If demand is decreased the normal two operation load can be increased to four, thus halving normal output. Thus, the ability to vary the number of operations in worker assignments provides the company with a method to match output productivity with changing demand requirements.

Since this approach is not restricted to use only in Japan it would not be accurate to label JIT as a system which is not capable of handling demand uncertainty. However, it is recognized that it would require American companies to make major changes in plant layout and job classifications of workers.

With the above concepts defined and the information derived from the review of literature, the following additional research propositions are suggested:

1. JIT is effective at reducing important cost factors, therefore profit with JIT should exceed profit without JIT.

2. It is possible to have just materials management JIT or just physical distribution JIT but these "part-way" systems should produce less profit than system-wide JIT.

3. Under materials management only JIT, required inventory costs will be reduced, while under physical distribution only, JIT inventory costs will increase (meeting the increased service level of the customer's JIT system with a conventional materials management and inventory control system would likely require increased inventory).

4. With system-wide JIT, uncertainty in materials management will severely impact profit performance, but demand uncertainty will not severely impact profit performance.

It would also be useful to compare the results of this study to the results of others who have investigated the effects of uncertainty on non-JIT distributions systems. From the demand uncertainty research of Speh and Wagenheim (1978) and Gross and Soriano (1969) and from (4.) above, the following additional propositions are suggested:

5. Materials Management operational uncertainty has a greater negative impact on profit performance than demand uncertainty.

6. Materials Management operational uncertainty has a greater negative impact on service performance than demand uncertainty.

From the review of JIT and physical distribution service (PDS) literature, it was noted that JIT requires high PDS levels to operate as intended (to provide material "just in time" without stockouts). It was not shown that JIT insures high service levels under all operating conditions. The development of problems (shortages, delays, quality problems,...) would have more of a negative effect on a JIT system than on a Non-JIT system (due to the inventory safety stock in the Non-JIT system). With this insight, an additional proposition concerning JIT's impact on service is suggested.

7. JIT does not does not automatically increase service levels under all conditions. It is conceivable that a Non-JIT system that holds a large safety stock will provide high service levels over a broader range of operating conditions than the system could with the safety stock removed and JIT applied.

All of these propositions can be detailed in a testable set of hypotheses for the response variable "profit" and a similar set for the "distribution service measure" response. Support for these hypotheses will be shown to be provided by General Systems Theory and by the results of previous research.

Research Hypotheses

Monden (1983) stated that the most important goal of the Toyota JIT System is cost reduction. Monden defines "the basic idea in such a system is to produce the kind of units needed, at the time needed, and in the quantity needed". Since this eliminates unnecessary intermediate and finished goods inventory, carrying costs and the costs associated with the risk of carrying inventory (obsolescence, damage, pilferage) can be greatly reduced. The benefits of JIT were demonstrated by Toyota's large profit in the face of the 1973 Japanese oil shock. "It would not be too much to say that Japanese companies have conquered the depression of oil shock (high cost-push inflation) by introducing the Toyota Production System (JIT) partially or totally" (Monden 1983).

Although JIT is often presented as a panacea, there has not been any total system research to support or reject this view. Even without any positive statistical results to support the hypothesis, the impact of JIT across test conditions must be tested. This hypothesis is basic to the question of "does JIT always have a positive profit impact or just under certain conditions?"

Other support can be found for this hypothesis in GST. Morris and Sirgy (1985) used the systems theory concepts of cybernetics (systems concerned with control mechanisms) and feedback (open adaptive systems responding to feedback from subsystems and the environment) as applied to marketing channels to derive the following proposition:

> "Adaptation level concept - A channel member is more likely to adapt and grow given that the channel member defines its role and objectives in the context of the channel network and more specifically as a function of the dominant channel member."

If "adapt and grow" suggest profitability and JIT is taken as an example of high channel coordination and cooperation, then GST lends further support to the hypothesis that JIT will have a positive profit effect.

Hahn, Pinto, and Bragg (1983) suggested conceptually that the potential benefits of JIT purchasing are numerous (i.e., reduced inventory levels, shorter delivery lead times, reduced safety stocks, improved quality levels and reduced costs through cooperative supplier product development activities).

Philipoom (1986) showed that JIT is feasible over a broader range of operating conditions than Monden (1983) described for the system in Japan. This finding suggests that American systems that do not meet ideal requirements may still benefit from JIT.

From the above positive findings the following is derived:

> H_1 The introduction of JIT in any configuration will have a significant positive effect on profit across all treatments.

Since the Toyota Production System is a successful system-wide JIT system, it is reasonable to expect that such full implementation will produce more positive results than either half-way system.

Again there is no previous research which investigated the superiority of system-wide JIT for profit performance compared to JIT only on the materials management or only on the physical distribution side. However, this is clearly supported by the GST tenet that "the whole is more than the collection of its parts" (Klir 1978). Also in GST, Morris and Sirgy (1985) derived the following proposition:

> "Hierarchy of control concept - A channel system is more likely to adapt and grow given that the behaviors of its channel members are fully coordinated with one another in a hierarchy of controls."

If once again "adapt and grow" is taken to imply profitability and system-wide JIT is recognized to be more fully coordinated than the part way systems (JIT on only the materials management or only on the physical distribution side), then GST can be said to support the hypothesis that system-wide profit performance will be superior to the two part way applications. Of the two half-way approaches, materials management JIT should produce higher profit because it involves inventory savings. A system which only has JIT on its physical distribution side allows its customer to reduce inventory levels (and associated costs) but may need to increase its own inventory levels to maintain PDS performance. From this the following is suggested:

H_2 System-wide (both sides) JIT will produce the greatest positive effect on profit, followed by materials management side and then physical distribution side (all under low uncertainty).

This hypothesis is made for low environmental uncertainty conditions because there is insufficient information to predict the response for all JIT alternative configurations under all combinations of uncertainty types and levels.

Forrester (1958) and Speh (1974) looked at the impact of demand uncertainty in conventional systems (non-JIT) and Huang, Rees, and Taylor (1984) looked at the impact of demand uncertainty on JIT systems.

Forrester's (1958) study (which was described in detail earlier) produced graphical results which suggested that costly fluctuations in production schedules occurred when demand variations were introduced. However, this result was based on an inflexible non-integrated, non-JIT system. The flexible nature of JIT operations should allow it to perform better.

Speh (1974), Wagenheim (1974), and Speh and Wagenheim (1978) (which have also been described earlier) also investigated a non-JIT systems and found the statistically significant results ($\alpha = .05$) that the presence of high demand uncertainty did not significantly increase total system cost, but did have a negative impact on service.

Huang, Rees, and Taylor (1984) (which was also described earlier) found (without statistical hypothesis testing) that overtime increased as variability in demand increased. The model incorporated JIT but did not represent the total system, only the production operations which were represented as inflexible. The analytical results of these studies on non-JIT systems cannot be used to support hypotheses of how JIT should be expected to perform under similar conditions. The non-JIT study results do however provide a basis for comparison. No one has yet compared these results to the impact of materials management operational uncertainty. As discussed previously, Monden (1983) stated that conceptually the Toyota JIT System meets fluctuations in demand through flexibility. If JIT can still have a positive profit impact in the presence of demand uncertainty the impact of demand uncertainty should be less than the impact of materials management operational uncertainty which JIT would be helpless to adapt to (the only options would be to add inventory or stock-out). This suggests:

H_3 With system-wide JIT, profit will be negatively impacted more by high materials management operational uncertainty than by high demand uncertainty.

From the GST perspective Morris and Sirgy (1985) derive the following:

> "Channel systems that are fully and vertically integrated....are less responsive to environmental demands."

If JIT is taken as a more fully vertically integrated system than non-JIT system, then GST suggests that JIT will suffer more in the face of high environmental uncertainty of both types (materials management operational and demand) than a non-JIT less integrated system.

H_4 System-wide JIT will be negatively impacted in profit more by high materials management uncertainty and demand uncertainty than a non-JIT system.

Speh and Wagenheim (1978) stated that "in the presence of high levels of demand uncertainty the total cost of the system did not vary significantly". This can be tested by the hypothesis:

H_5 High demand uncertainty does not result in lower profit as compared to low demand uncertainty.

Interactions are expected based on the GST tenet that the whole is more than the sum of its parts (Klir 1978). Interactions will be discussed in detail in the Factorial Design section. From that discussion the following will be justified:

H_6 The presence of both materials management JIT and physical distribution JIT will produce a positive synergistic effect on profit.

H_7 The presence of both high materials management operational uncertainty and high demand uncertainty will produce a negative synergistic effect on profit.

The question of JIT's relationship with service has never been explored. JIT by definition presupposes high service levels. There are however some treatments that will most likely not allow JIT to maintain the high service levels necessary to operate effectively. If demand is reasonably consistent, the simple forecasting element in the model will be able to keep the system in "tune" and maintain high service levels. As demand becomes more uncertain, stock-out problems will reduce service levels. While this demand uncertainty will pose a serious problem, materials management operational uncertainty should pose an even greater problem. Any means of forecasting such uncertainty is lacking and JIT should be helpless to react to it. This gives the following additional hypotheses:

H_8 The introduction of JIT in any configuration will not have a significant positive effect on service across all treatments.

H_9 With system-wide JIT, service will be negatively impacted more by high materials management operational uncertainty than by high demand uncertainty.

By the suggestion that JIT implementation does not in itself guarantee an increase in service level and by the upcoming discussion of interaction effects, the following are derived:

H_{10} The presence of both materials management JIT and physical distribution JIT will not produce a positive synergistic effect on service.

H_{11} The presence of both materials management operational uncertainty and demand uncertainty will produce a negative synergistic effect on service.

With these hypotheses stated the next step in computer simulation will be undertaken.

SPECIFY SYSTEM PARAMETERS

The second step according to Lee, Moore and Taylor (1981) (Figure 2) is to specify the system parameters and decision rules of the real-world system which will be represented in the computer simulation. Similar to the Karrenbauer (1980) model, the model to be used for JIT research represents operation at a transactional level of detail (the dynamic operating procedures of the complete distribution system). The model has a high degree of resolution and realism in representation of day-to-day events between the sources of supply, distribution centers, branch warehouses and customers. Orders will be generated and filled, branch inventories will be depleted and have to be replenished from distribution centers, which similarly will order replacement stock from their sources of supply. Capacity limits may be exceeded and limitations or storage expansion may be required. In general, the model elements incur costs and earn profits in much the same manner as a real operation as traced by its financial or operational data system. It is this output which will produce data which can then be analyzed to establish relevant relationships.

COMPUTER MODEL DEVELOPMENT

The GPM (Global Planning Model) to be used in this study was introduced in an earlier section. The creation of the model itself is not the subject of this study. Rather, this study is concerned with the use of the GPM model as a research instrument to investigate alternative distribution systems. As such, the structure of the model from a programmer's perspective will not be covered.

The model was developed by a team of Virginia Tech students under the direction of Dr. John T. Mentzer and is meant to be adaptive and to reflect the operation of a variety of actual distribution systems. Figure 3 represents the modular subsystems present in the Global Planning Model. To initialize the model the user interacts with the logistics simulator module to define the multi-echelon nature of the channel (or company). In the logistics simulator (Figure 4) 1 to s material suppliers can be defined along with which products they supply to which next echelon channel members. Similarly, 1 to d distribution centers (or manufacturers) can also be defined. Sales branches 1 to b are also established along with the products they provide to 1 to m markets.

To provide the model with the system parameters and decision rules of the real world system, the elements in each cost center must be established for all channel members. For example, the following might be defined for a branch:

Cost Center 1. MATERIALS HANDLING

receiving - fixed = $10,000 per period

shipping - fixed = $5,000 per period
- variable = $.91/100 pounds shipped

materials handling supervision
- fixed = $8,500 per period

.
.
.

Cost Center 2. ORDER PROCESSING

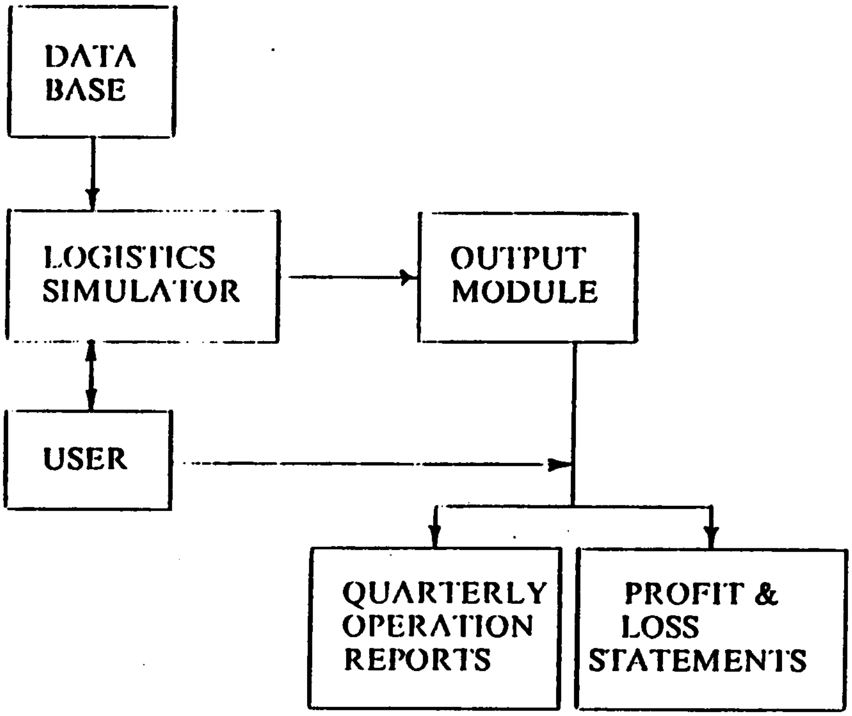
supervision - fixed = $15,000 per period
- variable = $.20/ number of lines received

telephone - fixed = $115 per period
- variable = $0.10/ number of orders received

office supplies

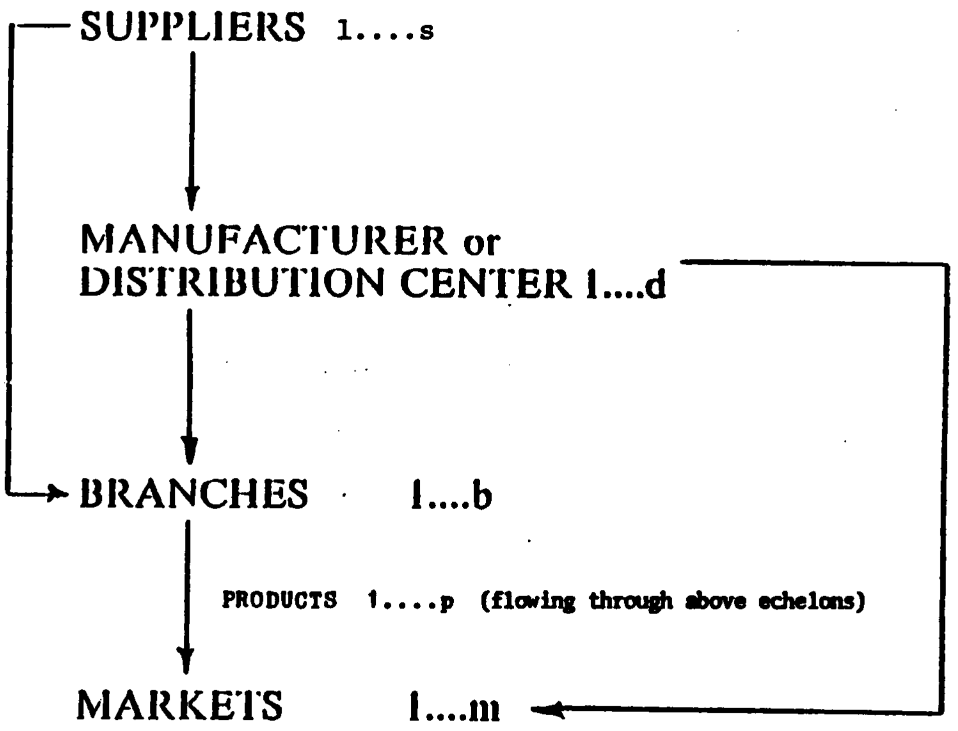
EDP charges

.
.
.



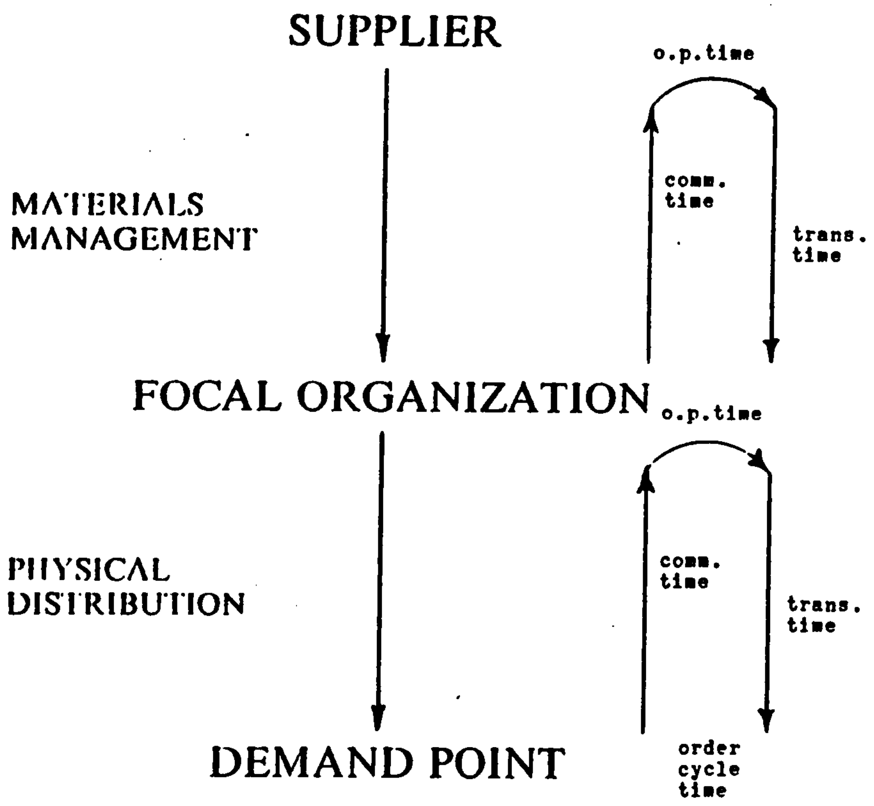
GLOBAL PLANNING MODEL

FIGURE 3



LOGISTICS SIMULATOR

FIGURE 4



CHANNEL CONFIGURATION

FIGURE 5

For the purposes of this study a simple distribution channel will be represented (Figure 5). This simple channel consists of a focal organization with a supplier (source of supply) providing needed material and a demand point (customer) requesting finished goods. From the point of view of the focal organization, the flow of material from the supplier is controlled under a materials management system. When this part of the system utilizes JIT procedures it is referred to as materials management JIT. The materials management order cycle time can be seen in Figure 5 between the focal organization and its supplier. The components of the materials management order cycle time are communication time (to get the order request to the supplier), supplier order processing time and lastly the transportation time to move the material from the supplier to the focal organization. Materials management operational uncertainty is operationalized as either a large or small variance in the materials management order cycle time. For the focal organization such uncertainty is beyond their control and must be recognized as a real world variable which must be faced. While past studies provide an indication of what realistic values of these variables could be, the actual values for the simulation will not be set until after pilot run analysis.

On the other side of the focal organization, demand must be satisfied by the movement of finished goods to the customer. From the point of view of the focal organization this movement is physical distribution and it can be operated with or without a JIT approach. The order cycle time on this side (shown in Figure 5) is from the customers point of view and along with "percent orders filled" make up the important measures of physical distribution service previously discussed. The variance in physical distribution order cycle time is an element partially inside the control of the focal organization (by virtue of its ability to increase production or amount of inventory carried). Thus, physical distribution order cycle time is not totally an outside uncontrollable element to be recognized as an additional factor. The purpose of this research is to investigate the effects of outside factors on JIT systems, rather than to investigate the effects of internally flawed JIT systems. It would not be reasonable to cross the factor "physical distribution JIT" with a factor such as "high physical distribution uncertainty". A system cannot be based on product arriving Just-in-Time but in an uncertain manner. This would be the same as Just-in-Time that is Not-Just-in-Time. Such a system would not be capable of Just-in-Time operation as it has been defined in this study.

On the other hand, demand uncertainty (operationalized as a large or small variance in the quantity ordered) is a realistic outside factor with an effect on JIT which should be investigated. The specific independent variable factors and dependent variable responses to be used in this research will be further defined and justified in later sections.

VALIDATE MODEL

Before utilizing a computer model in an experiment it must be tested for correctness. In trying to determine this correctness two concepts are considered (Fishman and Kiviat 1968). The first is referred to as "verification" and includes determining whether the model performs as intended (debugging the programming logic and code) and the second concept "validation" concerns establishing that the model responds as the real-world system which it is meant to represent.

Verification (debugging) is completed before validation since the programming must be correct before the model can be compared to the real world. To begin verification the random number generators should be tested for uniformity of distribution by a "chi-square" test and for independence by a "runs" tests (Law and Kelton 1982). Similarly a "chi-square" test may be used to test the distribution by which the random numbers are creating random variables in the model.

Most computer produced random number sequences are generated by the recursive solution of a "linear" congruential generator function such as:

$$z_i = (a\ z_{i-1} + c)\ (\mathrm{mod}\ m)$$

where

z_i = the i^{th} random number

z_{i-1} = the $i\text{-}1^{th}$ random number

a = a multiplier constant

c = an increment constant

mod m = modulus m: an operation which requires division by the value of m and the retention of only the portion of the answer which is right of the decimal point.

Law and Kelton (1982)

To test that the number sequence produced is uniformly distributed between zero and one, a "chi-square" test can be used with the null hypothesis that the sequence is uniform. The test procedure requires dividing the 0-1 space into a number of subintervals (say k=100 equal subintervals). If n=1000 numbers are produced and the sequence is perfectly uniform, then n/k=10 should fall in each subinterval. This would result in a $\chi^2 = 0$ which indicates absolutely uniformity. Actual results will not be perfectly uniform and the χ^2 test will indicate how close is close enough (that is to some α significance level). The test statistic is:

$$\chi^2 = \frac{k}{n} \sum_{j=1}^{k} (f_i - \frac{n}{k})^2$$

where:

f_i = the number of observations which fall in the i^{th} subinterval

The null hypothesis is rejected for $\chi^2 > \chi^2_{(k-1)(1-\alpha)}$ which is the $(1-\alpha)$ critical point on the χ^2 distribution for $(k-1)$ degrees of freedom.

Law and Kelton (1982)

To test a number sequence for independence a "runs" test can be used. A simple runs test considers "one run" as any group of sequential observations which are all above or below the expected value (e.g., if the sequence starts below .5, the run continues until a value is encountered above .5, which ends the below run and begins an above run). For example: .01, .45, .20, .56, .89, .11, .35 would represent three runs. Here the first run consists of .01, .45, .20, the second run consists of .56, and .89. The remaining values of .11 and .35 would be a third run. Too few or too many runs would indicate a pattern. How many is too few or too many must be determined by formal hypothesis testing.

For a large sample size, a normal distribution will approximate the distribution of the test statistic:

$$Z = \frac{R - (2\ n_1\ n_2/[n_1 + n_2]) - 1}{\text{SQRT}\ [((2\ n_1\ n_2)(2\ n_1\ n_2 - n_1 - n_2))/((n_1 + n_2)^2\ (n_1 + n_2 - 1))]}$$

where:

R = number of runs

n_1 = number of observations > .5

n_2 = number of observations < = .5

A classical normal distribution hypothesis test can be done:

H_o = independent and random

H_a = not independent and random reject $Z_{obs} > 1.96$ which is critical point for $\alpha = .05$ two tail test.

After the verification is complete, the correctness of the model's representation is investigated by validation testing. Meier, Mewell and Pazer (1969) suggested the following validation procedures:

1. short model runs compared to hand calculations
2. verify model segments separately
3. replace stochastic elements with deterministic
4. use simplified probability distributions
5. use simple test data inputs

A number of other techniques exist for further model validation (Kleijnen 1974, Mihram 1972). Chi-square and Kilmogorov-Smirnov tests can be used to compare simulation output frequencies with the historical output of the real-world system. Factor analysis and spectral analysis can also be used to test that the factor loadings and spectra are the same for both outputs. A simple regression analysis could be done between the outputs to test if the intercept is zero and the slope is one. Theil's inequality coefficient could also be used to test the statistical equivalence of the two output number streams.

The GPM model has been completely validated (prior to this dissertation) for use in representing these specific types of multi-echelon channel configurations.

DESIGN EXPERIMENTS

A large part of scientific reasoning and understanding has come from drawing conclusions from experiments that have been carefully designed, appropriately conducted, and properly analyzed (Ott 1984). When a computer model of a system is to be utilized, it is the execution of the simulation program which can be thought of as equivalent to a social or physical scientist conducting a laboratory experiment. Similar to such laboratory experiments, simulations are undertaken to determine what factors influence response variables of interest.

Factor List

The independent variables to be investigated in the JIT study consist of four factors, each with two levels:

Factor A - Materials Management Side JIT

- Level 1 - With Materials Management JIT
- Level 2 - Without Materials Management JIT

Factor B - Physical Distribution Side JIT

- Level 1 - With Physical Distribution JIT
- Level 2 - Without Physical Distribution JIT

Factor C - Materials Management Uncertainty

- Level 1 - Low Materials Management Operational Uncertainty
- Level 2 - High Materials Management Operational Uncertainty

Factor D - Demand Uncertainty

Level 1 - Low Demand Uncertainty

Level 2 - High Demand Uncertainty

Factorial Design

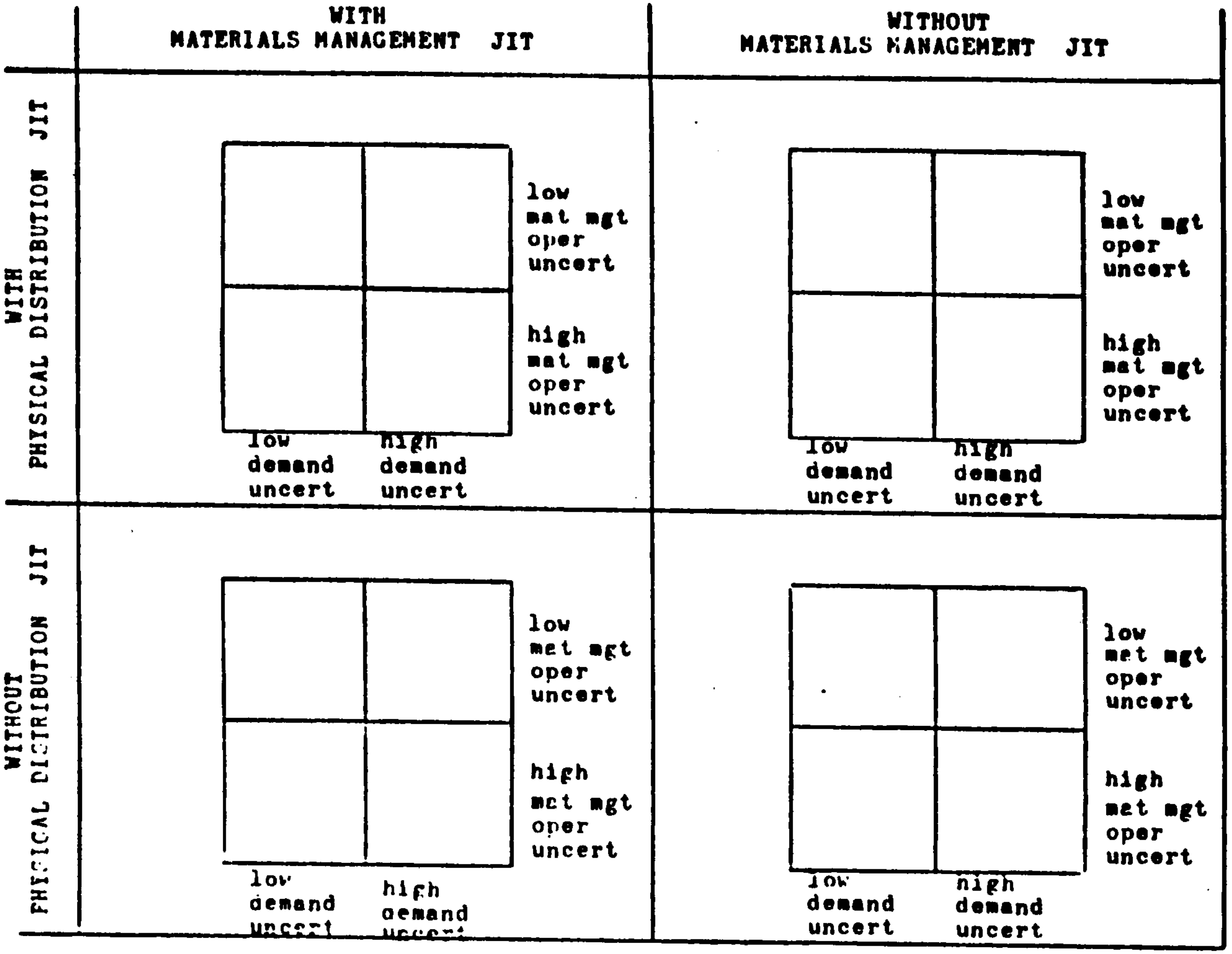
This suggests a 2 x 2 x 2 x 2 full factorial design with sixteen cells (see Table 4). For the purposes of statistical analysis each dependent variable will be investigated with an independent experiment. The question becomes "do the means of the 16 populations represented by the samples in the 16 cells differ or are they the same?" In order to infer that population means differ, the magnitude of random (within cell) variations must be measured. The essence of Analysis of Variance (ANOVA) is the making of inferences based on comparisons of between cell variance to within cell variance (Naylar, Balintfy, Burdick, and Chu 1966).

Beyond just finding that at least some factors affect the response variable, the identification of which factors produce what effects will have to be considered. This can usually be done by comparisons of column, row, or cell group means which represent the factors of interest. The main effect for a particular factor can be determined by the deviation of the cell group means (which represent the factor) and the grand mean.

Since it is desired to know which means differ from each other, multiple comparison procedures will be used. Many t tests could be used but the overall error rate would be large, so a multiple comparison procedure, with a controlled error rate (such as Tukey's, Duncan's, or

TABLE 4

2^4 FULLY CROSSED BALANCED FACTORAL DESIGN



Scheffe's) is preferred. Scheffe's method will be used in the JIT study since it is the most conservative, can be applied to any linear combination and is useful when many comparisons must be made.

It is possible that responses can be caused by more than just factor main effects and error. Factor interactions may also appear when the factors are not independent or independent but not additive as the assumed model suggests.

Two factors are said to interact if the difference in mean responses for two levels of one factor are not constant across levels of the second factor (Ott 1984). Higher level interactions are also possible if lower level interaction responses are not constant across levels of an additional factor. An interaction which is caused by non-additivity of independent factors can often be removed by a suitable transformation of the data (e.g., if multiplicative, logarithms may be used to restore additivity) (Naylor et al. 1966).

To illustrate the possibility of interaction effects when factors are not independent, Mihram (1972) provides the following example.

> "Although the qualitative variate (which describes, say, queue discipline in a simulation model) might prove to augment the system's productivity if it is altered from FIFO (0 level) to LIFO (1 level), and although a second qualitative factor (which describes, say, the use of exogenous weather conditions) might also tend to augment the similar response if summer rather than winter conditions are employed, the combination of LIFO queue discipline and summer weather need not result in an improvement that is exactly the sum of the improvements of their individual effects. Rather, their combined presence might either enhance or retard the expected similar response; in either event, the interaction is present."

This research study will investigate the possibility that there will be an (AB) interaction between Factor (A) Materials Management JIT and Factor (B) Physical Distribution JIT when both are present. Since system wide JIT is expected to be superior to JIT applied to a portion of the system, this (AB) interaction is expected to be a positive synergistic effect. Similarly, the presence of both Factor (C) Materials Management operational uncertainty and Factor (D) Demand uncertainty may lead to a negative synergistic effect (CD).

Assumed Model

The use of ANOVA implies the acceptance of a set of assumptions. The first in the JIT study is that the dependent variable response can be represented by the model:

$$\begin{aligned} Y_{ijklm} &= \mu + A_i + B_j + C_k + D_l + (AB)_{ij} + (AC)_{ik} \\ &+ (BC)_{jk} + (AD)_{il} + (BD)_{jl} + (CD)_{kl} \\ &+ (ABC)_{ijk} + (ABD)_{ijl} + (ACD)_{ikl} + (BCD)_{jkl} \\ &+ (ABCD)_{ijkl} + E_{ijklm} \end{aligned}$$

where

Y_{ijklm} = individual dependent variable response value for the i^{th} materials management JIT alternative,
j^{th} physical distribution JIT alternative,
k^{th} materials management uncertainty alternative,
l^{th} demand uncertainty alternative, and
m^{th} replication

A_i = main effect of Materials Management side JIT

$i = 1,2$

B_j = main effect of Physical Distribution side JIT

$j = 1,2$

C_k = main effect of Materials Management uncertainty

$k = 1,2$

D_l = main effect of Demand uncertainty

$l = 1,2$

μ = grand mean

E_{ijklm} = residual variation not accounted for by the model

m = number of simulation replication

(xx) = two way factor interactions

(xxx) = three way factor interactions

(xxxx) = four way factor interactions

If the assumption of this model is not correct it can be expected that the experimental error residual term will be large.

Three other basic assumptions of ANOVA are that the experimental errors are normally and independently distributed with a constant variance. In the case of computer simulation, experimental error is a random effect dependent on the random number generator. It contains none of the typical unwanted social science experimental effects which may influence subject response (learning, hypothesis guessing, prior knowledge, age, etc.) This suggests that experimental error is under experimenter control and that random assignment to cells is unnecessary.

In simulation, the experimental errors are made independent by using independently generated sequences of random numbers in each run. Given a large number of replications the Central Limit Theorem would ensure normality and equal variance. Even for the small number of replications expected in the JIT study, Scheffe has shown the F test to be robust even with non-normality and unequal variances as long as the number of observations per cell is equal (Kleijnen 1974).

Variance Reduction

An important aspect in planning research is to minimize the effects of factors not of current interest. As previously stated, simulation implies a great deal of experimental control. In non-simulation experimentation reduction of variation often calls for increasing the amount of data. However, with stochastic simulation the experimenter can manipulate the random number generator and decrease variation with a cost of the loss of some independence. Such manipulations are referred to as variance reduction techniques. The purpose of a variance reduction technique is to reduce the variance of an estimator by replacing the original sampling procedure by a new procedure which yields the same expected value but with a smaller variance (Kleijnen 1974).

An often used variance reduction technique in simulation is "Common Random Numbers" where the same sequence of random number seeds is used in each cell. In the process of generating possible values for (stochastic) random variables a series of (0.0 - 1.0) random numbers is created by a generator function and a numerical starting point (seed).

Given the same seed the generator function will always produce the same series of random numbers. A different seed will result in a different series of random numbers. Law and Kelton (1982) provided algorithms for transforming a stream of independent, identically distributed uniform random numbers into various distributions. If the same sequence of random number seeds is used in each cell, the first observation in cell one will be produced by the same random number stream as the first observation in each of the remaining cells. This would be similar to using the same series of subjects in each cell to reduce unexplained variance. Further, the random numbers can be "synchronized" so that a number used for a particular purpose in the first replication in cell one is used for the same purpose in the first replication of the all other cells. Given the complexity of the JIT model such synchronization would be very difficult. In the course of a simulation the GPM model will request a great many random numbers from a number of generators. Different treatments will impact the number and timing of these requests making the possibility of true synchronization very unlikely.

Although such variance reduction is attractive and is equivalent to factor blocking in the terminology of social science experimental design, its effectiveness cannot be determined before hand. The issue can only be resolved during the pilot run stage.

Response Variables

Another important aspect of planning is the choice of measures of response variables. In computer simulation these can be measured directly and in the JIT study will consist of:

1. Profit (total in dollars for the focal organization)
2. Order Cycle Time (physical distribution) Mean (in days)
3. Order Cycle Time (physical distribution) Variance (in days)
4. Percent (customer) Orders Filled

Variable 1 is self evident as a measure of financial performance. However, it is important to note that the term "profit" is being used here to represent an aspect of profitability rather than in its usual accounting definition. In an actual calculation of accounting profit the distribution of fixed expenses would have to be considered. Since fixed expenses and many other expenses will be constant across treatments, they will not be considered. The responses will be referred to as profit for convenience, but will be in fact be portions of marginal income. Since treatments will be compared to each other, the result will not be affected.

Variables 2, 3, and 4 are intended to be indicators of physical distribution service (PDS). The individual importance of PDS elements has previously been shown to be situation specific, therefore the three measures will not be formally combined into a total PDS level.

It may be recalled that Mentzer, Gomes, and Krapfel (1989) suggested that the three elements of PDS were; (1) availability, (2) timeliness and (3) quality. Percent orders filled (response variable four) provides the measure of availability while order cycle time mean and variance (response variables two and three) provide the measure of timeliness. Some measure of "quality" would be useful for a complete analysis, but suitable operational measures are not available in the model output.

Mentzer, Gomes, and Krapfel (1989) defined the following operational measures for the "quality" element:

(1) percent items received in acceptable condition per order

(2) percent items are correct items per order

(3) percent items are in correct quantity per order

The problem with these measures is that simulation models most often represent the entire quality element by a value (such as returned goods) which is set as a function of some other value, usually sales dollars or shipment quantity. Since the model does not recognize sales elasticity to service performance, the quality response would not be a true one. Simulation response variables should be the result of interaction within the system. For this reason quality measures were not judged suitable and will not be used as a component of PDS in this study.

A last important aspect in planning is to carefully choose the subjects. This concern is not relevant to simulation. Unlike other social science experimental designs, stochastic simulation does not need protection from subject or systematic variation by randomization of subjects, treatments, nor run orders (Law and Kelton 1982). The only errors introduced are generated by the random number generators.

PERFORM SIMULATION

Prior to performing the simulation there are several aspects of the JIT simulation which will have to be resolved with the observation of pilot runs.

Start Up and Transient Period

The usual procedure to control for this problem is to determine the length of the start up transient period and to delete this period from the analysis. The extent of the transient period is influenced by the system initialization. In the case of the JIT study, the normal operating state of some treatments will vary greatly from the normal operating state of others (JIT system-wide and on the materials management side implies low inventory levels, the others do not). This difference in the normal state means that the extent of the transient period will be of concern. This is due to the inability to initialize the runs at values close to common normal states. For example, starting the model with the starting value of inventory at EOQ plus safety stock will not be a burden to those configurations which hold significant inventory. On the other hand, this starting point will be a burden to system-wide JIT which holds little inventory (the end of the transient period will not be reached until the initial inventory is worked off). A number of past studies have used formal statistical methods to determine the truncation point (Wilson and

Pritsker 1978). While others have just observed the warm up period while the initial set of orders clear the system and then made a subjective determination that the system had settled down (Grasso 1982).

Stochastic Convergence

Another issue to be addressed by the pilot runs is the nature of the response of the model. A "steady state" simulation is one in which the output is defined with respect to a limit as the length of the simulation becomes infinite, while a "terminating" simulation's output will be measured relative to specific starting and stopping points (Kelton 1983). The JIT model is expected to be handled as a terminating simulation; however if the model settles down to a steady state response early, the effect of starting with a different random number may be small and the model may be better analyzed using batch means (intermediate value means) or just the steady state value rather than replications. This is not expected to be the case because stochastic convergence is characteristically a slow process (Naylor et al. 1966).

Sample Size

The last issue addressed by the pilot runs is the question of sample size (number of replications per cell). The concept of sample size in computer simulation is more complex than the concept of sample size in real world experiments (Naylor et al. 1966). In simulation, the benefits of increased sample size may be gained by (1) increasing the number of replications, (2) increasing the run length or (3) reduction of the time unit to provide more data. If the termination length is set at some period and the time unit is set at discrete days, the concern of sample size in the JIT study is a question of number of replications per treatment condition.

It should also be considered that the power of the test to detect an effect increases with the number of replications (n). This must be weighed against the cost in time and expenses to make the additional runs (Mihram 1972). To establish (n), a method that is often used in computer simulation is to repeat the experiment until the variance of the estimated output parameters is less than some preset values (Maryanski 1980). Alternatively, one can estimate (n) from the confidence interval equation using the sample variance from the pilot runs and a desired confidence interval width and precision (Law and Kelton 1982).

Both Karrenbauer (1980) and Grasso (1982) found five replications to provide significant accuracy in computer studies similar in scale to the JIT study. Five replications is therefore chosen as the starting point for the JIT study.

CHAPTER IV

FINAL TEST CONDITIONS AND EXPERIMENTAL RESULTS

FINAL TEST CONDITIONS

The last two items shown on the Figure 2 representation of the simulation process are "Simulation Output in the Form of Operating Statistics" and "Analyze Simulation Results". These issues will be the covered in this fourth chapter after a brief review of the results of the preliminary pilot tests.

Before utilizing the GPM model for this investigation, several specifics about its setup and operation were investigated. Pilot runs and specially programed runs were made to investigate such areas as, uniform random number generation, distribution generation, transient period, sample size, and variance reduction.

RANDOM NUMBER GENERATION

The tests of uniform random number generation were conducted as described in Chapter III. The results of the "chi-square" test for goodness of fit with a uniform distribution are in Table 5.

Distribution fit results can vary dramatically with degrees of freedom. In a chi-square analysis for fit, the distribution is split into a number of cells, and the number of observations which fall into each cell is compared to the theoretical number expected. The number of cells assigned sets the degrees of freedom. The decision as to how close a fit is required is subjectively made by the researcher based on factors such as how the number stream is to be used in the model, the amount of numbers to be drawn from it, and the cost versus the benefits of improving it given the restraints of the model. The results shown on Table 5 give an indication of the fit of two samples of 500, divided into a reasonable number of cells.

Similar fit tests were run on samples of number streams taken from the demand distribution generator. The results of these tests are listed on Table 7.

The "runs" test for pattern in the number sequence was also completed with the results shown on Table 6. All of these tests indicate that the number sequences produced are not perfect, but they were judged to be within acceptable limits for use in the model. Given the very large numbers of samples to be drawn from these distributions, the central limit theorem suggests that minor variations in the original distributions should not be significant.

TABLE 5

TESTS FOR FIT OF THE RANDOM NUMBER STREAM WITH A UNIFORM DISTRIBUTION

SAMPLE 1

Sample size = 500
Chi-square = 63.04
Degrees of freedom = 37
significance level = .005

SAMPLE 2

Sample size = 500
Chi-square = 48.32
Degrees of freedom = 37
significance level = .101

TABLE 6

TESTS FOR RANDOMNESS BY RUNS TEST

SAMPLE 1

Sample size = 500
Runs above and below median = 272
Expected number = 251
Sample test statistic, Z = 1.84
Two-tailed probability = .065

SAMPLE 2

Sample size = 500
Runs above and below median = 271
Expected number = 251
Sample test statistic, Z = 1.75
Two-tailed probability = .081

TABLE 7

TESTS FOR FIT OF THE FUNCTION PRODUCING THE DEMAND DISTRIBUTION

SAMPLE 1 - Low Demand Uncertainty

Sample size = 2000
Chi-square = 86.1
Degrees of freedom = 26
significance level = <.001

SAMPLE 2 - High Demand Uncertainty

Sample size = 2000
Chi-square = 39.1
Degrees of freedom = 26
significance level = .047

MODEL OPERATIONALIZATION

The actual simulation of the channel configuration shown in Figure 5 was simplified by the elimination of variables which would not be affected by the treatments. This mainly involved items which were considered fixed by accounting policy. The model then had to be restricted from taking actions which would change the actual values eliminated from financial consideration. For example, in the study of material flow through the channel, the expansion of plant facilities by the model would confound the effects of the factors of interest.

Particular values for variables within the model(i.e., labor rates - $/hour, order processing rates - orders/hour, and order picking and packaging - lines/hour) were chosen from values suggested by Lambert and Stock (1984) and also from Cashin and Polimeni (1981). Having a realistic ratio between these variables and their consistent use across treatments was seen as more critical than their specific values. Test runs were made at various treatment levels to insure that the chosen variables would result in realistic model responses across the domain of the experiment. The importance of this process was demonstrated when it was found that the original operationalization of JIT, while functional, did not in fact operate in the manner of a true JIT system. This problem was solved prior to running the actual experiment.

The independent variables were operationalized by setting certain variable values in the model. The GPM model allows the specifying of an inventory carrying policy for each location in the channel. At each location either a JIT or a conventional inventory policy was specified (depending on which of the 16 treatments were being simulated). The JIT inventory policy was programed to not accumulate requirements, but would respond to an order with an immediate order of its own to its supplier. The alternative conventional inventory policy operated with a reorder point in days and an economic order quantity calculated by the model. The stochastic variables of materials management operational uncertainty and demand uncertainty were operationalized by adjusting the standard deviation of the transportation time, and customer demand distributions. The specifics of these procedures can be seen in Table 8.

Tables 9 and 10 show the general treatment specification and the detail of each cell treatment.

TABLE 8

INDEPENDENT VARIABLE OPERATIONALIZATION
(four factors with two levels each)
(DC1 represents the supplier organization)
(DC2 represents the focal organization)
(DC3 represents the customer organization)

FACTOR A - Materials Management JIT

Level 1 with Materials Management JIT
in DC2, DC X Product Matrix

Variable Name	Value
#29 Ordering Policy	4 (just-in-time)

[i.e., The ordering policy at the focal organization (DC2) is set to operate JIT. Holding a minimum of inventory, it must order material to satisfy each new demand.]

Level 2 without Materials Management JIT
in DC2, DC X Product Matrix

Variable Name	Value
#29 Ordering Policy	1 ROP/EOQ
#30 ROP in days	6 if low mm uncertain
	(8) if high mm uncertain
#31 EOQ Policy	1 (calculated by model)

FACTOR B - Physical Distribution JIT

Level 1 with Physical Distribution JIT
in DC3, DC X Product Matrix

Variable Name	Value
#29 Ordering Policy	4 (just-in-time)

Level 2 without Physical Distribution JIT
in DC3, DC X Product Matrix

Variable Name	Value
#29 Ordering Policy	1
#30 ROP in days	6 if low mm

		uncertain
	(8)	if high mm uncertain
#31 EOQ Policy	1	(calculated by model)

FACTOR C - Materials Management Operational Uncertainty

Level 1 Low Materials Management uncertainty in DC2, DC X Product Matrix

Variable Name	Value
#38 Primary Average Transit Time	3
#39 Primary Low Transit Time	2
#40 Primary High Transit Time	4

Level 2 High Materials Management uncertainty in DC2, DC X Product Matrix

Variable Name	Value
#38 Primary Average Transit Time	3
#39 Primary Low Transit Time	0
#40 Primary High Transit Time	6

FACTOR D - Demand Uncertainty

Level 1 Low Demand Uncertainty in DC3, DC X Product X Market Matrix

Variable Name	Value
# 8 Average Unit Sales	1000
# 9 Low Unit Sales	700
#10 High Unit Sales	1300

Level 2 High Demand Uncertainty in DC3, DC X Product X Market Matrix

Variable Name	Value
# 8 Average Unit Sales	1000
# 9 Low Unit Sales	100
#10 High Unit Sales	1900

TABLE 9

GENERAL TREATMENT SPECIFICATION

ABCD	
1000	With Materials Management JIT
2000	Without Materials Management JIT
0100	With Physical Distribution JIT
0200	Without Physical Distribution JIT
0010	Low Materials Management Uncertainty
0020	High Materials Management Uncertainty
0001	Low Demand Uncertainty
0002	High Demand Uncertainty

TABLE 10

DETAIL OF CELL TREATMENTS

TREATMENT	FACTOR A	B	C	D
1111	With mm JIT	With PD JIT	Low mm Uncer	Low Demand Uncer
1112	With mm JIT	With PD JIT	Low mm Uncer	Hi Demand Uncer
1121	With mm JIT	With PD JIT	Hi mm Uncer	Low Demand Uncer
1122	With mm JIT	With PD JIT	Hi mm Uncer	Hi Demand Uncer
2111	W/O mm JIT	With PD JIT	Low mm Uncer	Low Demand Uncer
2112	W/O mm JIT	With PD JIT	Low mm Uncer	Hi Demand Uncer
2121	W/O mm JIT	With PD JIT	Hi mm Uncer	Low Demand Uncer
2122	W/O mm JIT	With PD JIT	Hi mm Uncer	Hi Demand Uncer
1211	With mm JIT	W/O PD JIT	Low mm Uncer	Low Demand Uncer
1212	With mm JIT	W/O PD JIT	Low mm Uncer	Hi Demand Uncer
1221	With mm JIT	W/O PD JIT	Hi mm Uncer	Low Demand Uncer
1222	With mm JIT	W/O PD JIT	Hi mm Uncer	Hi Demand Uncer
2211	W/O mm JIT	W/O PD JIT	Low mm Uncer	Low Demand Uncer
2212	W/O mm JIT	W/O PD JIT	Low mm Uncer	Hi Demand Uncer
2221	W/O mm JIT	W/O PD JIT	Hi mm Uncer	Low Demand Uncer
2222	W/O mm JIT	W/O PD JIT	Hi mm Uncer	Hi Demand Uncer

TRANSIENT PERIOD

A beginning inventory value (common across treatments) was chosen which would minimize the transient period. The objective was to specify enough beginning inventory that the treatments which normally carried inventory could assume a reasonable ordering cycle without an immediate stockout, but not so much inventory that the treatments which carry little inventory would be burdened for a long period attempting to work it off. A detailed inside view of the model operating through this period was gained during the validation process when it was necessary to print out every action the model was taking (e.g., orders received, inventory calculations, shipments outbound, and transit times). With the insight afforded by this procedure the decision was made that the transient period was one to three weeks and would not have a significant effect beyond the first simulated month.

SAMPLE SIZE

As discussed in Chapter III, sample size in simulation (n) can be determined from the standard deviation of the pilot runs (s), the normal distribution value for the desired confidence level (Z), and the size of the confidence interval width that will be acceptable (+/- E).

For comparison, sample size was calculated for two confidence levels (α = 90%, α = 95%) and two confidence interval widths (E = 1.0% of the mean, E = 1.5% of the mean). Using data from the highest uncertainty cell of the response variables, the formula $n = [Z s / E]^2$ was used to produce the data shown in Table 11 (Ott 1984).

The objective was to arrive at a common sample size which would be acceptable for all of the response variables (in terms of confidence level and interval) and also practical (in terms of time and resources).

After reviewing Table 11 a decision was made to increase the number of replications to ten per cell (from the originally planned five per cell). Each cell treatment would contain ten runs, with each run consisting of one simulated year. At a confidence interval of +/- 1.0% of the mean, n = 10 should produce a confidence level of between 90% and 95%. The confidence level should exceed 95% for many of the response variables, and the sample size will not be so great as to force significance in the results.

TABLE 11

SAMPLE SIZE DETERMINATION

Confidence Interval +/-	1.0% mean		1.5% mean	
Confidence level	90%	95%	90%	95%
Pilot Response Variable 1	n = 9	12	4	6
Pilot Response Variable 2	2	2	1	1
Pilot Response Variable 3	6	8	3	4

VARIANCE REDUCTION

As expected, the variance reduction techniques discussed in chapter III (common random numbers and synchronization) were not found to be practical or necessary in this application. When the simulations were run and the results analyzed by analysis of variance, the data seemed to reflect reasonable treatment effects even without control of the random number stream.

In reviewing the data prior to input, it was noticed that some of the performance measures seemed to be affected by the particular level of demand experienced. It seemed logical that some runs would get demand level from the high or low end of the distribution and that this could inhibit or improve performance. For example, a run that happened to get a larger demand might have a greater opportunity to earn profit if stock was available or greater opportunities to stock-out if stock was not available. Similar situations could arise for the other dependent variables.

A decision was made to collect total customer demand data for each run and to evaluate the effect of including it in the analysis as a covariate. The analysis of covariance adjusted the treatment means for differences in covariate level. A comparison of the analysis of variance values for R-squared (coefficient of determination - the proportion of the variability in the dependent variable that is accounted for by the model) and MSE (mean squared error - residual variation not accounted for by the model) are in Table 12. In all cases, the presence of the covariate reduced MSE and increased R-squared.

A problem with using R-squared as a criterion is that it increases with each additional predictor variable, even when the new variable has very little predictive power. For dependent variables which showed minor increases in R-squared, the use of ANACOVA would not be supported.

To further investigate the impact of demand, the simple linear regression correlation coefficient between it and each of the dependent variables was calculated. The values of R indicate that demand had a strong positive correlation with profit (R = 0.7168), a weak negative correlation with percent orders filled (R = - 0.4039), and inconsequential correlation with order cycle time (R = 0.2052), and standard deviation of order cycle time (R = - 0.0146). This finding seems intuitive, profit increases with increasing demand, fill rate decreases with increasing demand, and order cycle time is not affected by demand.

Additional tests were conducted to justify the use of the covariance model with profit and possibly percent orders filled. Tests for the appropriateness of ANACOVA are based on the assumptions of the model in addition to the assumptions of ANOVA. The additional assumptions of ANACOVA include:

1. Treatments have no affect on the covariate.
2. The regression slope coefficients are equal for all treatment groups.
3. The relationship between the dependent variable and the covariate is linear within each treatment group.
4. The covariate is measured without error. (Horton 1978)

With an understanding of the simulation programming it is clear that the total demand could not be a function of the JIT and materials management independent variables (Assumption 1). Assumption 2 presented more of a problem. Statistically, the profit cell treatments failed Assumption 2 at alpha = .05. At least one treatment's regression slope coefficient was not equal to the rest. With sixteen treatments for each dependent variable this was not surprising. Since the F test is fairly robust to this violation (Horton 1978), and since the overall relationship between profit and total customer demand proved to be acceptably linear (Assumption 3), a decision was made to use ANACOVA for the analysis of the profit response. This was based on the judgment that the method would provide more insight into the data than it would be likely to mask.

In the case of the remaining response variables the use of ANACOVA provided minor improvement in R^2 and minor reduction in MSE, as indicated in Table 12. The correlation coefficients previously mentioned in this section also indicated weak correlation between the remaining response variables and the demand covariate.

The gain in precision from the use of ANACOVA depends primarily on the size of the correlation coefficient between the response and the covariate. "If the correlation coefficient is less than 0.3 in absolute value, the reduction in variance is inconsequential, but as the correlation coefficient mounts toward unity, sizeable increases in precision are obtained (Cochran 1971).

The correlation coefficient of the profit response (R = 0.7168) supported the use of the ANACOVA procedure. The weak correlations of the other response variables with demand (R = -.4039, .2052, -.0146) did not support the use of the ANACOVA procedure. Their analysis will use the more parsimonious ANOVA procedure. Test calculations indicated that, within this group, the results of mean comparisons would vary little with either analysis method.

TABLE 12

COMPARISON OF ANOVA AND ANACOVA RESULTS IN TERMS OF R-squared and MSE

(Major improvement in R-squared and MSE suggests that the use of ANACOVA should be considered)

Dependent Variable - Profit

ANOVA R-squared = 0.4750 MSE = 271610000.
ANACOVA R-squared = 0.8586 MSE = 73646000.

Dependent Variable - Order Cycle Time

ANOVA R-squared = 0.4349 MSE = 0.0129516
ANACOVA R-squared = 0.5206 MSE = 0.0110600

Dependent Variable - Standard Deviation OCT

ANOVA R-squared = 0.8451 MSE = 0.01293
ANACOVA R-squared = 0.8664 MSE = 0.01123

Dependent Variable - Percent Customer Orders Filled

ANOVA R-squared = 0.8386 MSE = 2.745205
ANACOVA R-squared = 0.8662 MSE = 2.291078

EXPERIMENTAL RESULTS

The experimental analysis on the 2 X 2 X 2 X 2 full factorial model followed a two step process: 1) analysis of variance, and 2) multiple comparisons of cell means procedures. The analysis of variance (covariance for the profit variable) must first reject the null hypothesis of equal cell means and also indicate that the main effects and interactions of interest are significant.

The wording of the research hypotheses indicated that they could be tested by measuring the significance of differences in combinations of cell means (by use of a multiple comparison procedure which requires an F test between two groups of cell means). Where the hypotheses stated a ranking of the averages of several cell means, multiple F tests were required. Thus, once the null hypothesis of equal cell means was rejected and the indication existed of significant main and interaction effects, it was appropriate to use multiple comparison procedures to test the research hypotheses.

ANOVA (ANACOVA)RESULTS

The analysis of variance (covariance for the profit response) tables which follow (Tables 13,14,15,16) will be used in a discussion of significant main effect and interactions. While the observations from these tables will be discussed here, the implications of these results will be reserved for Chapter V.

Of particular interest will be the significance of two way interactions. As discussed in Chapter III, two factors interact if the difference in mean response for two levels of one factor is not consistent across levels of the second factor. Following each variance analysis table are figures which illustrate the two way interactions taking place (Figures 6,7,8,9). Normally these plots would not be included in a discussion of results. However, in this study interactions are part of several hypotheses and will be important in the interpretation of mean comparison results.

Higher order interactions are also of concern, but for this study attempts at interpretation may not be practical.

TABLE 13

GLM ANOVA (ANACOVA)
Analysis of Covariance Report - PROFIT

```
-----------------------------------------------------

SOURCE    DF    SUM OF SQUARES    MEAN SQUARE    F VALUE

MODEL     16       6.397E10          3.998E9       54.30
ERROR     143      1.053E10          7.363E7       PR>F
ADJ TOTL  159      7.450E10                        0.0001

R - SQ    C.V.     ROOT MSE       MEAN
0.859     1.875    8580.928       457557.431

     Source         DF     TYPE I SS     F-Ratio   Prob>F

     X(DEMAND)      1      3.857E10      525.36    0.0001
     A              1      6.191E9       84.09     0.0001
     B              1      2.016E9       27.38     0.0001
     AB             1      1.444E9       19.61     0.0001
     C              1      5.647E9       76.70     0.0001
     AC             1      1.556E9       21.13     0.0001
     BC             1      2.216E8       3.01      0.0850
     ABC            1      1.781E9       24.20     0.0001
     D              1      1.950E9       26.49     0.0001
     AD             1      6.050E6       0.08      0.7748
     BD             1      1.657E9       22.50     0.0001
     ABD            1      1.073E8       1.46      0.2293
     CD             1      1.135E7       0.15      0.6952
     ACD            1      1.193E9       16.21     0.0001
     BCD            1      8.546E7       1.16      0.2831
     ABCD           1      1.421E9       19.30     0.0001

     Source         DF     TYPE III SS   F-Ratio   Prob>F

     X(DEMAND)      1      2.858E10      388.19    0.0001
     A              1      1.039E10      141.17    0.0001
     B              1      8.285E7       1.13      0.2906
     AB             1      1.463E9       19.86     0.0001
```

TABLE 13
(continued)

Source	DF	TYPE III SS	F-Ratio	Prob>F
C	1	8.071E8	10.96	0.0012
AC	1	1.551E9	21.06	0.0001
BC	1	1.707E8	2.32	0.1301
ABC	1	1.782E9	24.20	0.0001
D	1	4.627E9	62.83	0.0001
AD	1	6.056E6	0.08	0.7747
BD	1	1.610E9	21.86	0.0001
ABD	1	1.073E8	1.46	0.2293
CD	1	1.387E7	0.19	0.6649
ACD	1	1.193E9	16.20	0.0001
BCD	1	8.033E7	1.09	0.2980
ABCD	1	1.421E9	19.30	0.0001

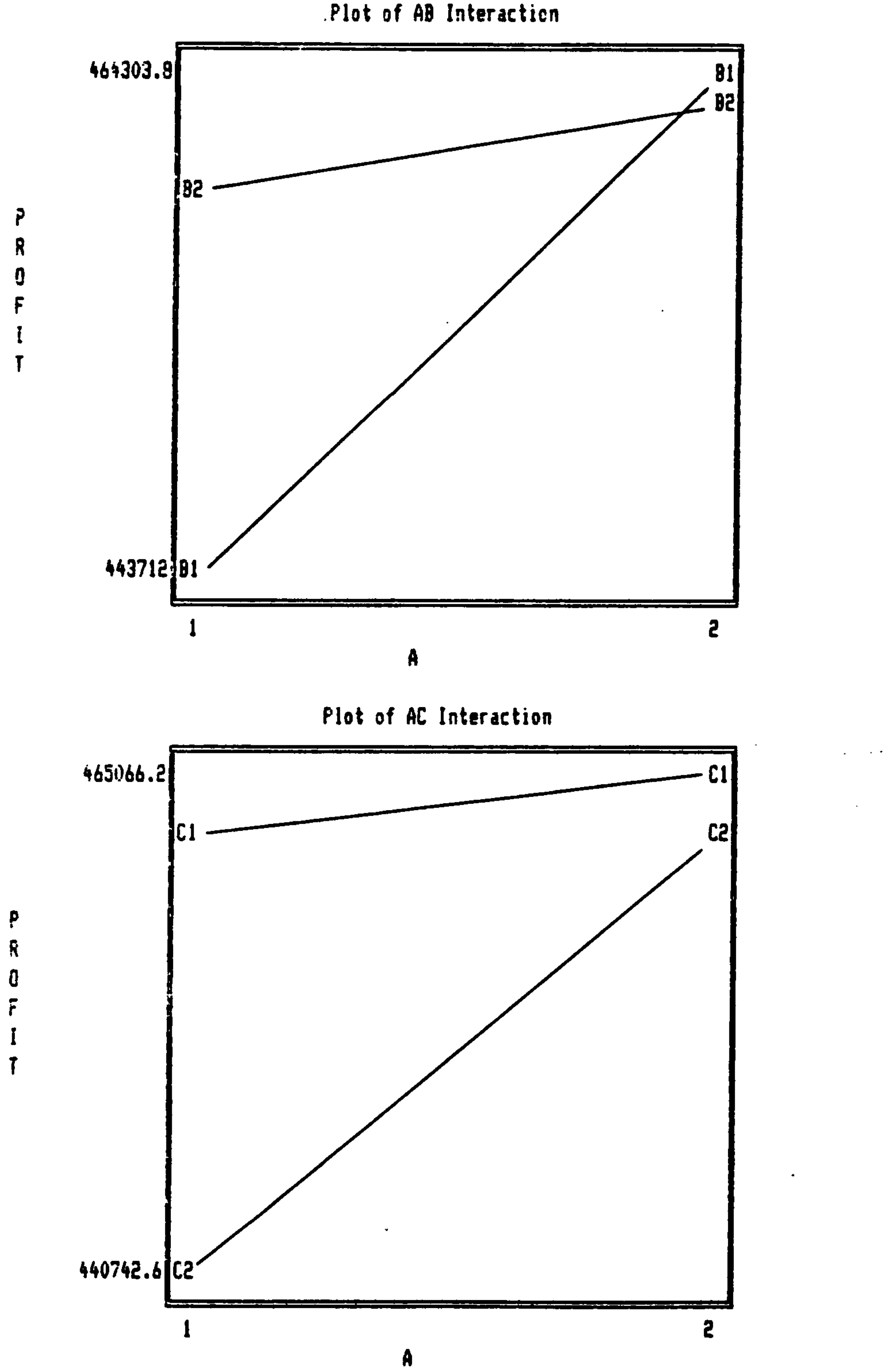
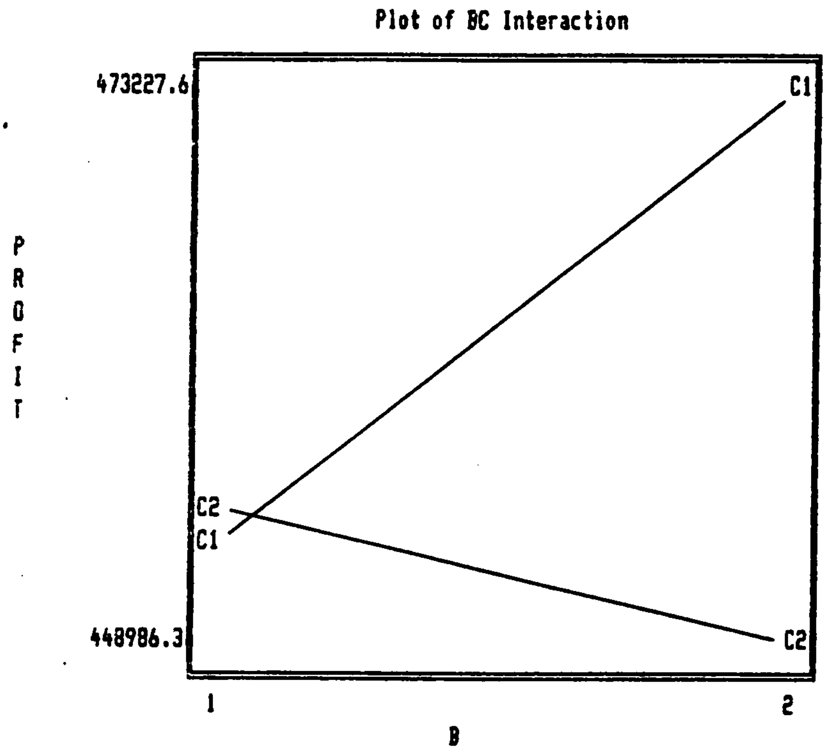


FIGURE 6

MAIN EFFECT INTERACTIONS FOR PROFIT



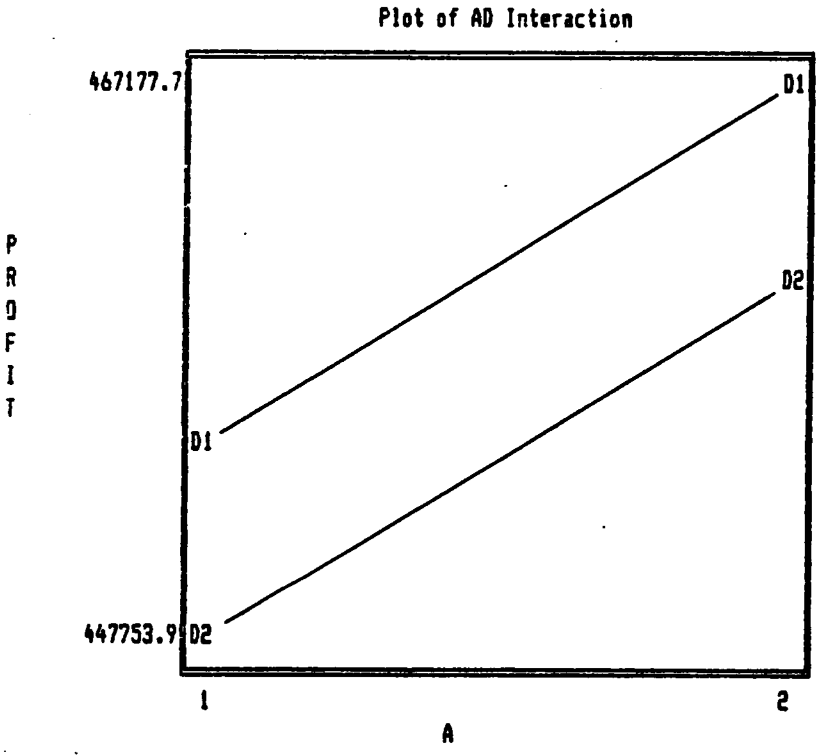
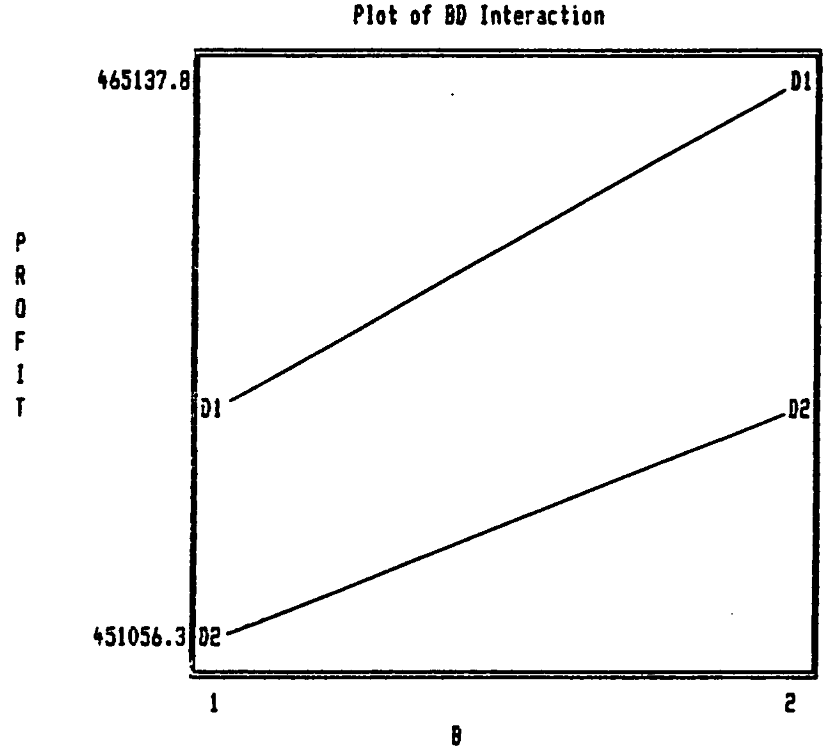


FIGURE 6 (continued)



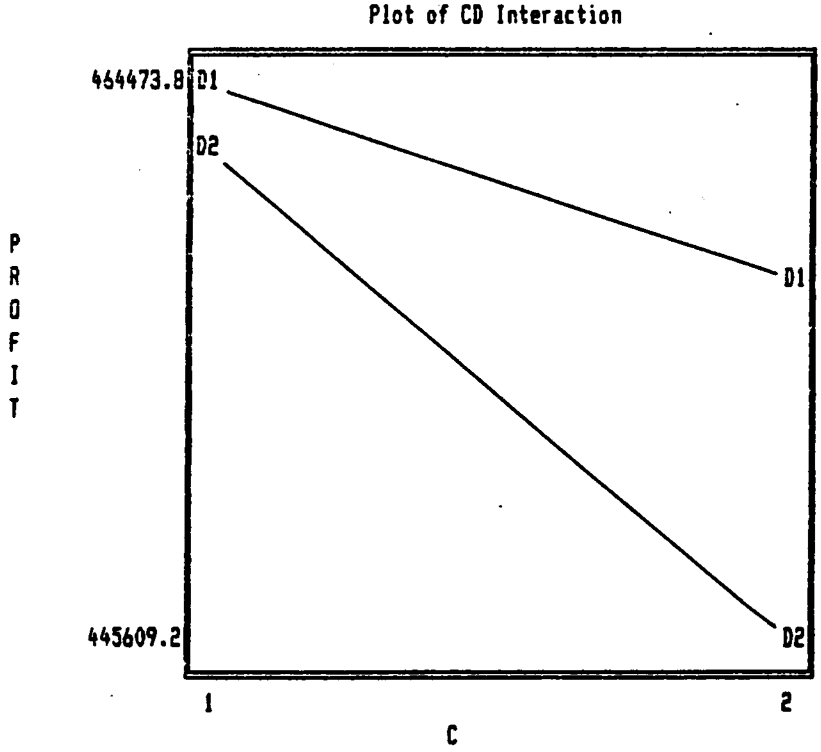
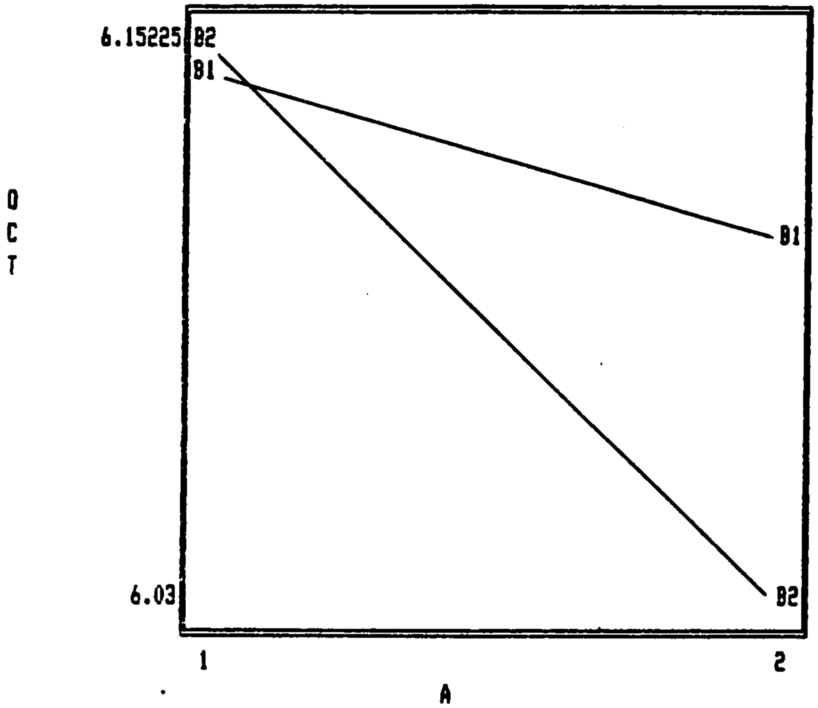


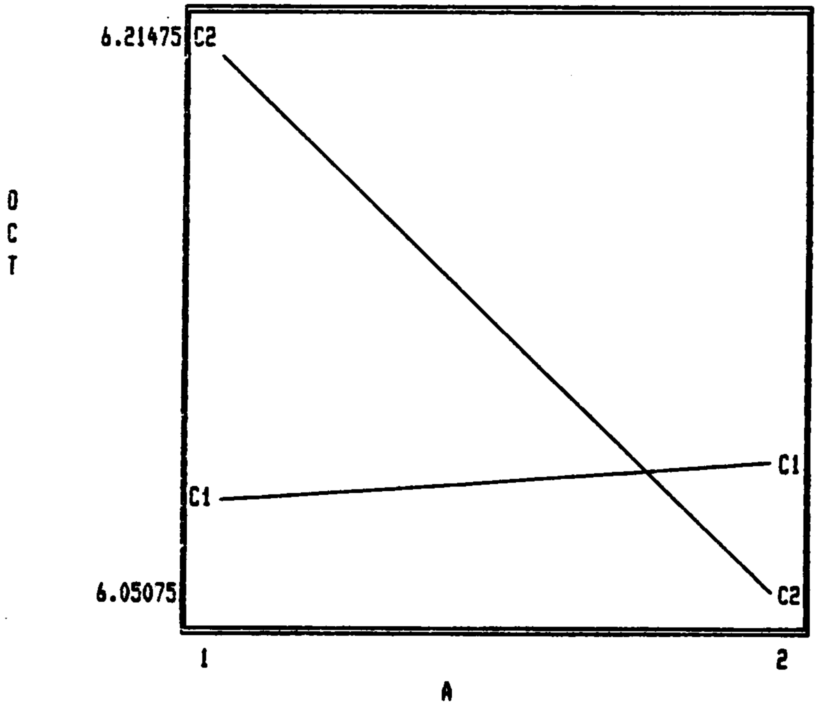
FIGURE 6 (continued)

TABLE 14

```
                           GLM ANOVA
         Analysis of Variance Report - ORDER CYCLE TIME
     ----------------------------------------------------

 SOURCE    DF   SUM OF SQUARES  MEAN SQUARE  F VALUE

 MODEL     15      1.435394       0.09569      7.39
 ERROR     144     1.865030       0.01295      PR>F
 ADJ TOTL  159     3.300424                    0.0001

 R - SQ    C.V.    ROOT MSE       MEAN
01486282   0.1138056.10931

     Source           DF     TYPE I SS    F-Ratio  Prob>F

     A                1      0.2379306    18.37    0.0000
     B                1      8.145E-02    6.29     0.0133
     AB               1      5.292E-02    4.09     0.0451
     C                1      8.789E-02    6.79     0.0102
     AC               1      0.3018906    23.31    0.0000
     BC               1      2.047E-02    1.58     0.2107
     ABC              1      9.360E-02    7.23     0.0080
     D                1      4.100E-03    0.32     0.5745
     AD               1      8.695E-02    6.71     0.0106
     BD               1      6.683E-02    5.16     0.0246
     ABD              1      6.930E-02    5.35     0.0221
     CD               1      4.192E-02    3.24     0.0741
     ACD              1      0.1066056    8.23     0.0047
     BCD              1      6.847E-02    5.29     0.0229
     ABCD             1      0.1150256    8.88     0.0034
```



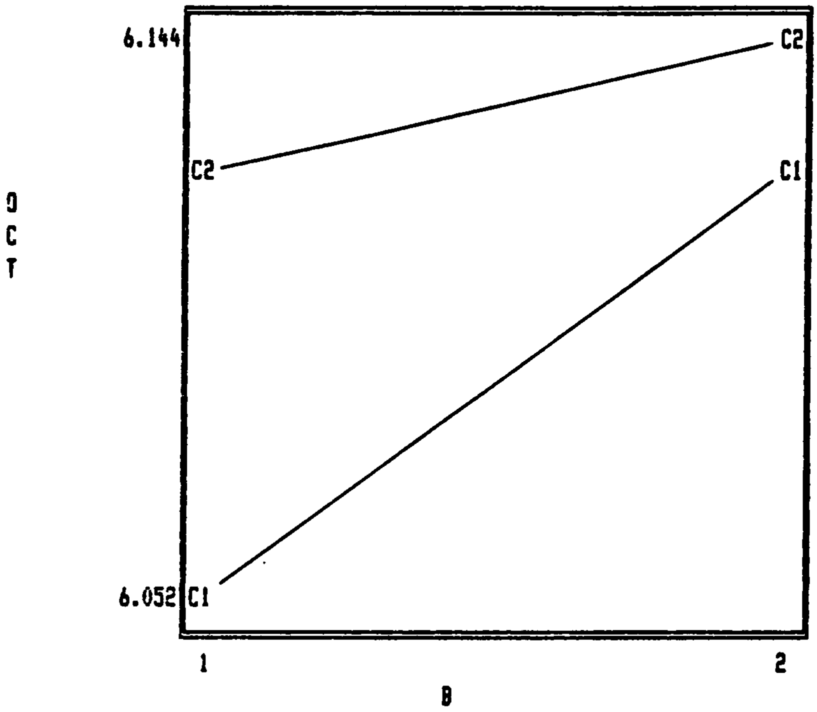
Plot of AB Interaction



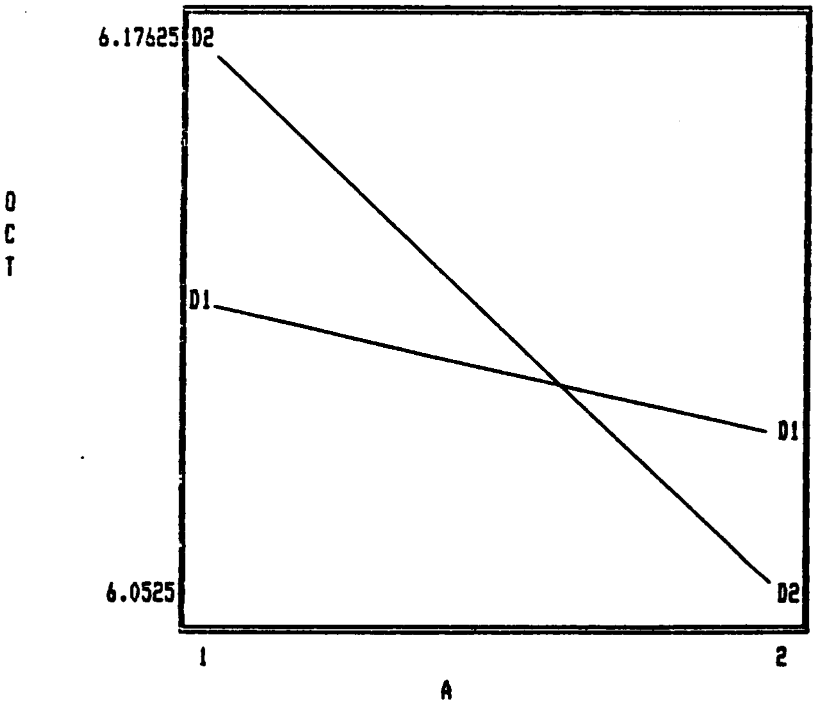
Plot of AC Interaction

FIGURE 7

MAIN EFFECT INTERACTIONS FOR
ORDER CYCLE TIME

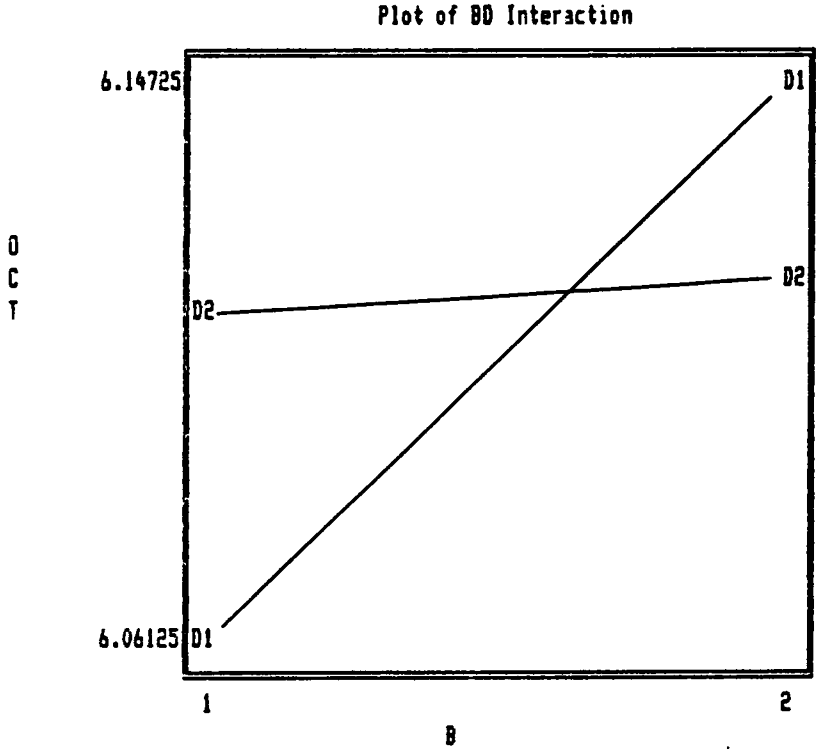


Plot of BC Interaction

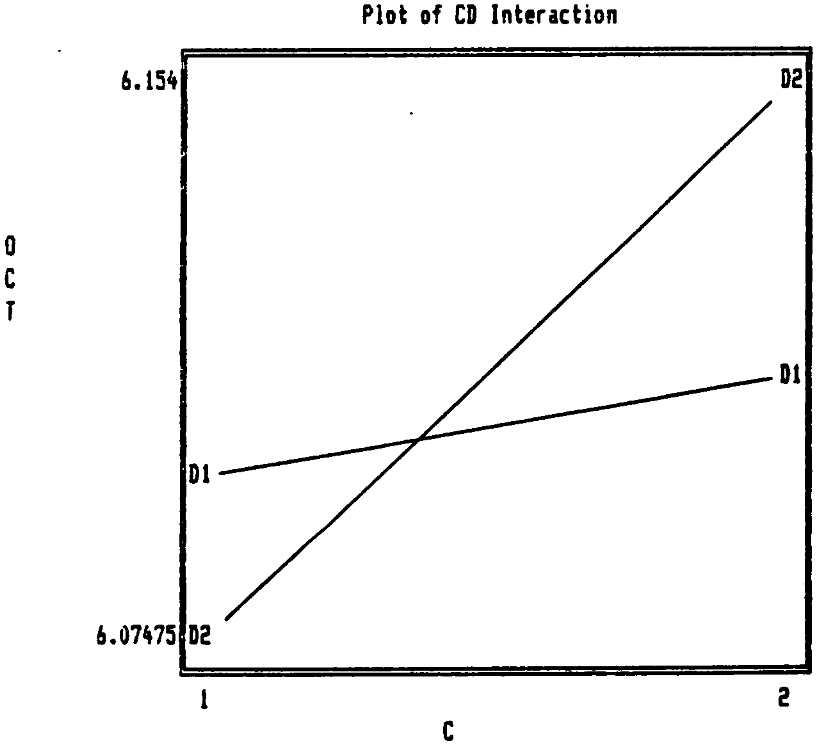


Plot of AD Interaction

FIGURE 7 (continued)



Plot of BD Interaction



Plot of CD Interaction

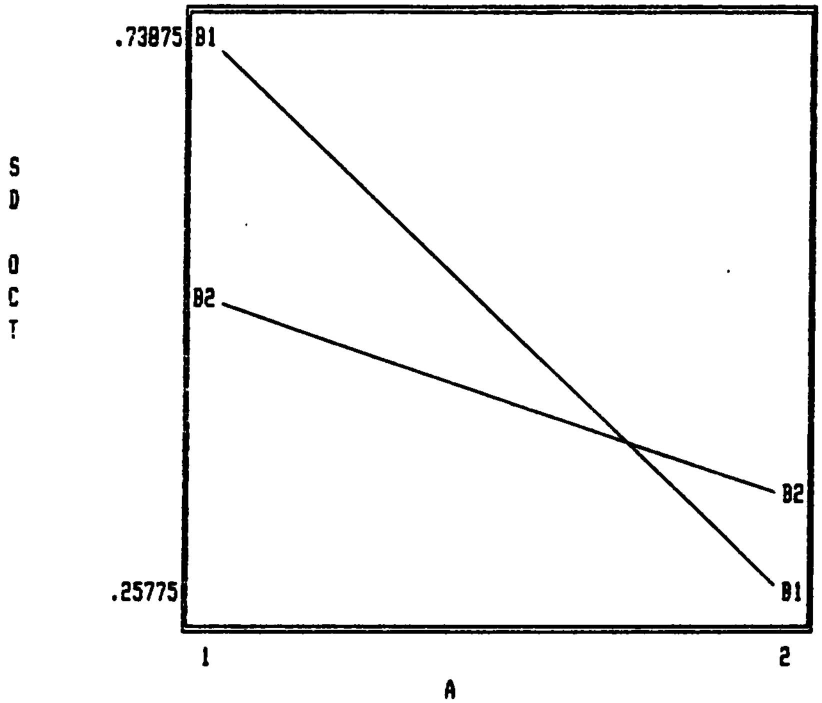
FIGURE 7 (continued)

TABLE 15

GLM ANOVA
Analysis of Variance Report - STANDARD DEVIATION OCT

```
-----------------------------------------------------

SOURCE    DF    SUM OF SQUARES    MEAN SQUARE    F VALUE

MODEL     15        10.16430        0.67762        52.39
ERROR     144       1.862500        0.01293        PR>F
ADJ TOTL  159       12.02680                       0.0001

R - SQ    C.V.      ROOT MSE        MEAN
02848538  0.1137280.45750

    Source          DF    TYPE I SS    F-Ratio  Prob>F

    A               1     4.218503     326.16   0.0000
    B               1     .26569       20.54    0.0000
    AB              1     .9765625     75.50    0.0000
    C               1     1.86624      144.29   0.0000
    AC              1     .6579225     50.87    0.0000
    BC              1     .36481       28.21    0.0000
    ABC             1     .1134225     8.77     0.0036
    D               1     .8094025     62.58    0.0000
    AD              1     .00001       0.00     0.9779
    BD              1     .0216225     1.67     0.1981
    ABD             1     .12996       10.05    0.0019
    CD              1     .1050625     8.12     0.0050
    ACD             1     .31684       24.50    0.0000
    BCD             1     .0525625     4.06     0.0457
    ABCD            1     .26569       20.54    0.0000
```

Plot of AB Interaction



Plot of AC Interaction

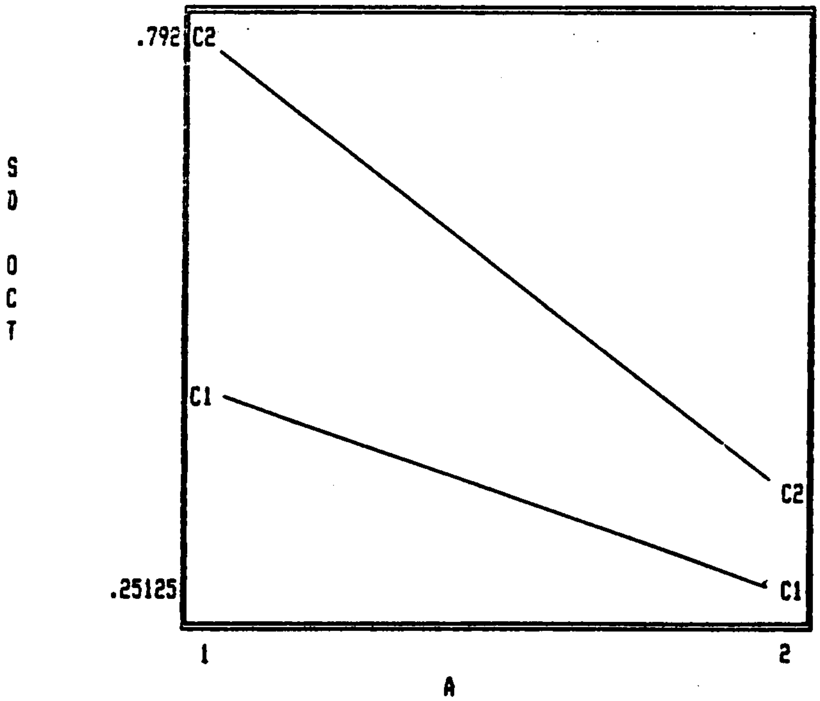
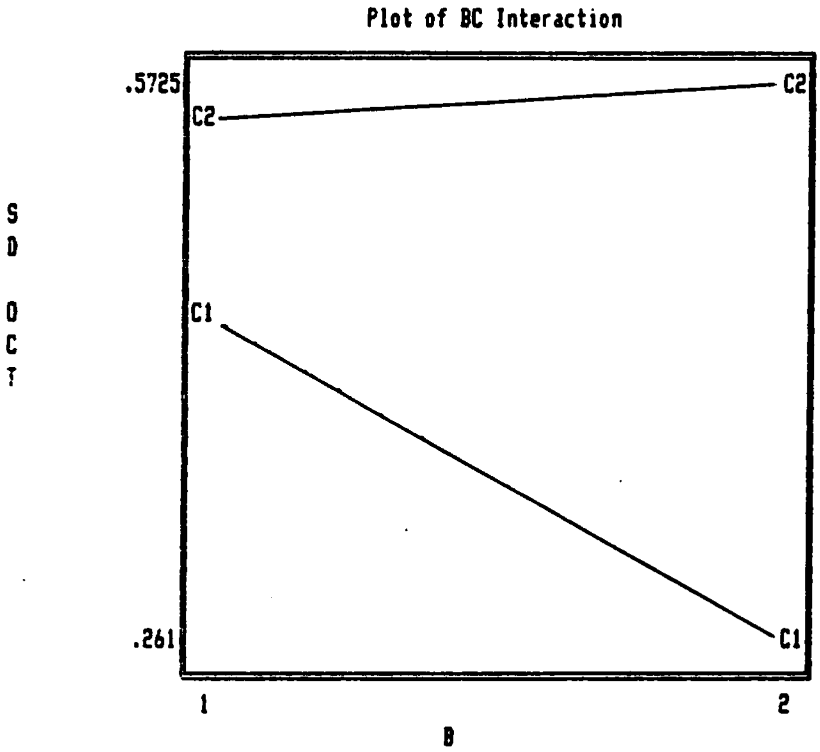
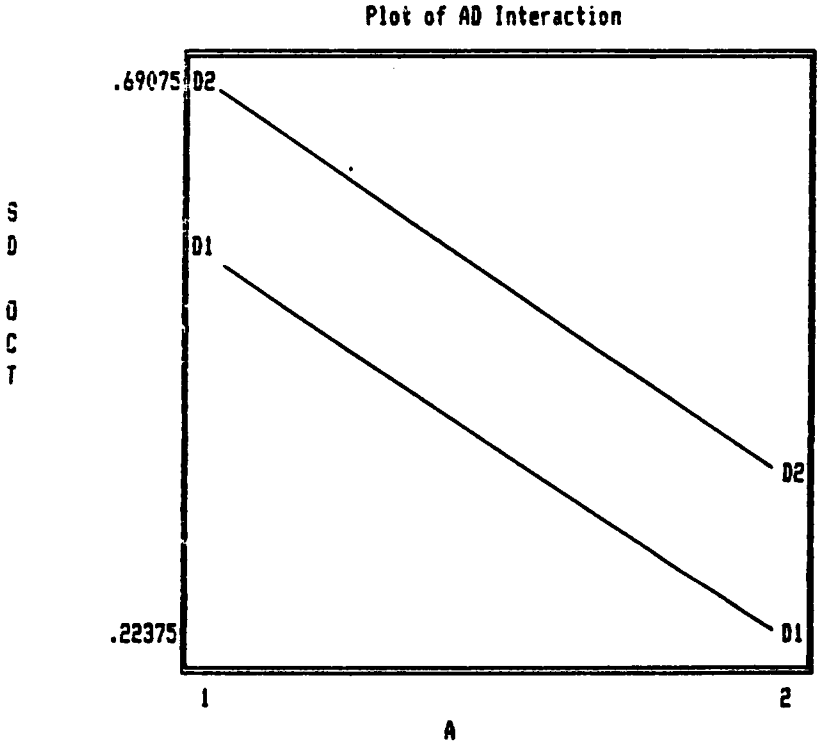


FIGURE 8
MAIN EFFECT INTERACTIONS FOR
STANDARD DEVIATION OCT

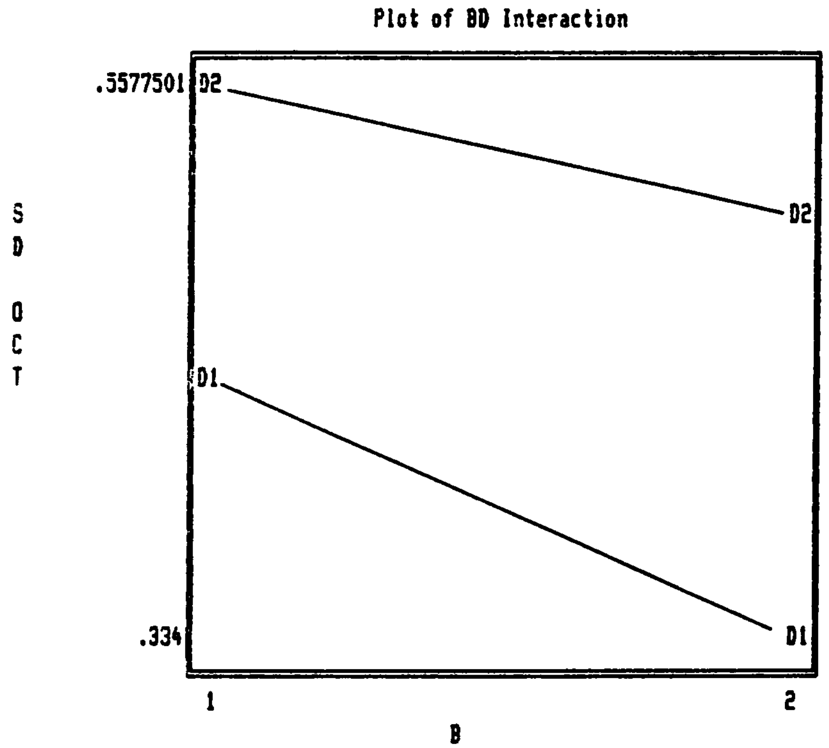


Plot of BC Interaction



Plot of AD Interaction

FIGURE 8 (continued)


Plot of BD Interaction

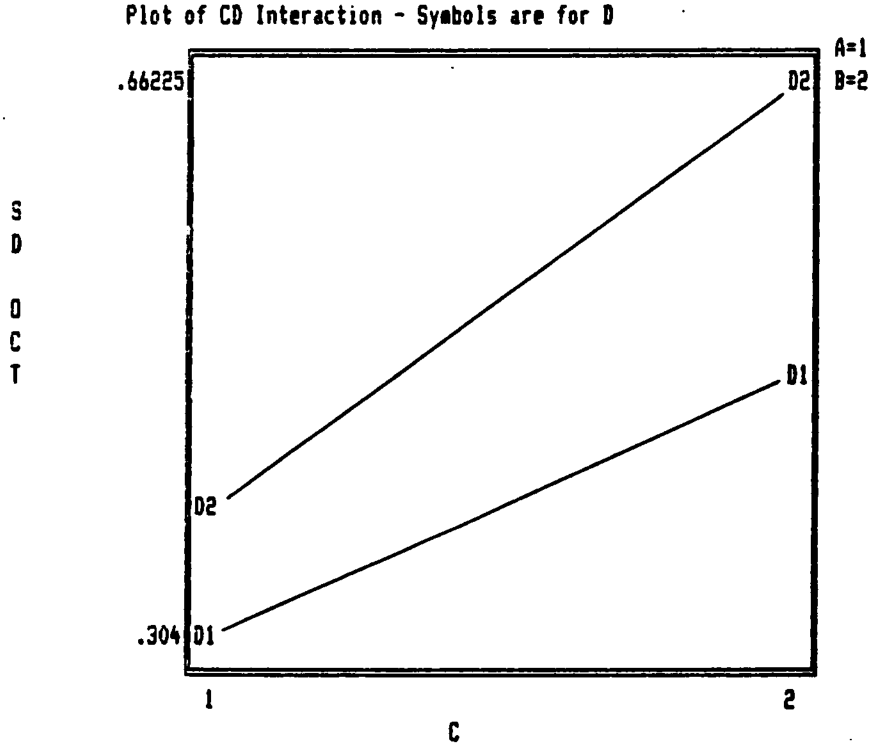
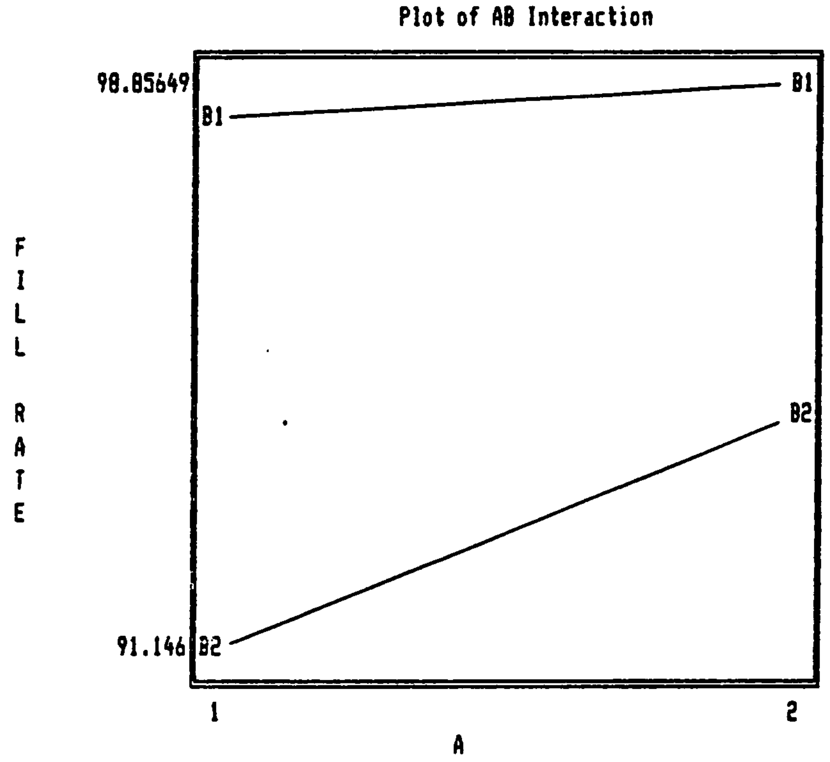

Plot of CD Interaction - Symbols are for D

FIGURE 8 (continued)

TABLE 16

GLM ANOVA
Analysis of Variance Report - PERCENT ORDERS FILLED

```
-----------------------------------------------------

 SOURCE    DF   SUM OF SQUARES   MEAN SQUARE   F VALUE

 MODEL     15      2053.880        136.925      49.88
 ERROR     144     395.3095        2.74520      PR>F
 ADJ TOTL  159     2449.190                     0.0001

 R - SQ    C.V.    ROOT MSE       MEAN
01838596   1.65686695.6762

     Source         DF    TYPE I SS    F-Ratio  Prob>F

     A              1     113.9063     41.49    0.0000
     B              1     1451.061     528.58   0.0000
     AB             1     72.9         26.56    0.0000
     C              1     3.56409      1.30     0.2564
     AC             1     53.91684     19.64    0.0000
     BC             1     .15376       0.06     0.8133
     ABC            1     47.82969     17.42    0.0001
     D              1     161.122      58.69    0.0000
     AD             1     3.86884      1.41     0.2371
     BD             1     61.25625     22.31    0.0000
     ABD            1     .54289       0.20     0.6572
     CD             1     .361         0.13     0.7174
     ACD            1     40.84441     14.88    0.0002
     BCD            1     .61009       0.22     0.6381
     ABCD           1     41.94304     15.28    0.0001
```


Plot of AB Interaction

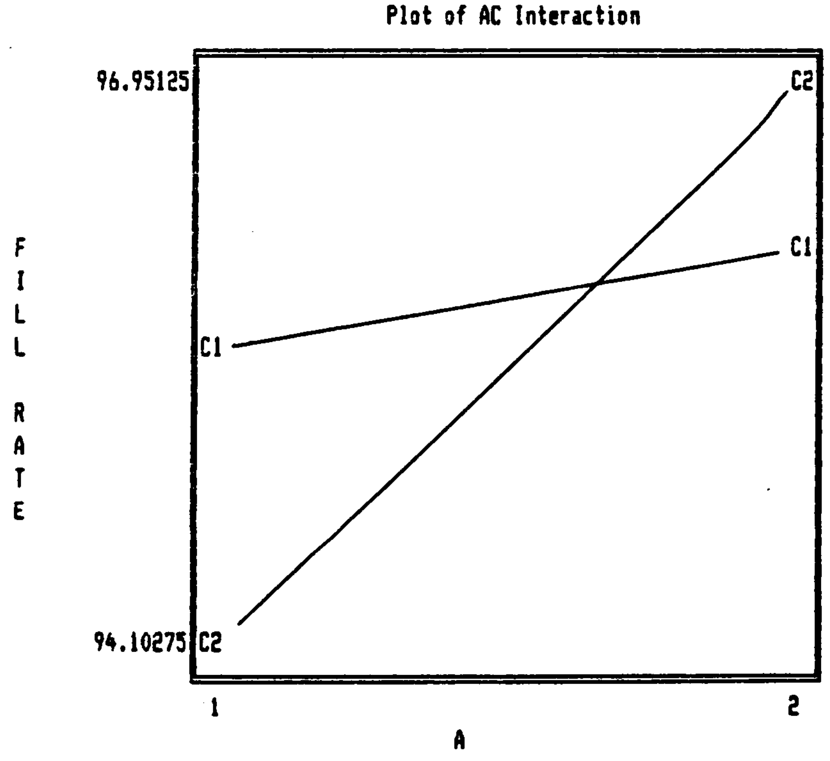
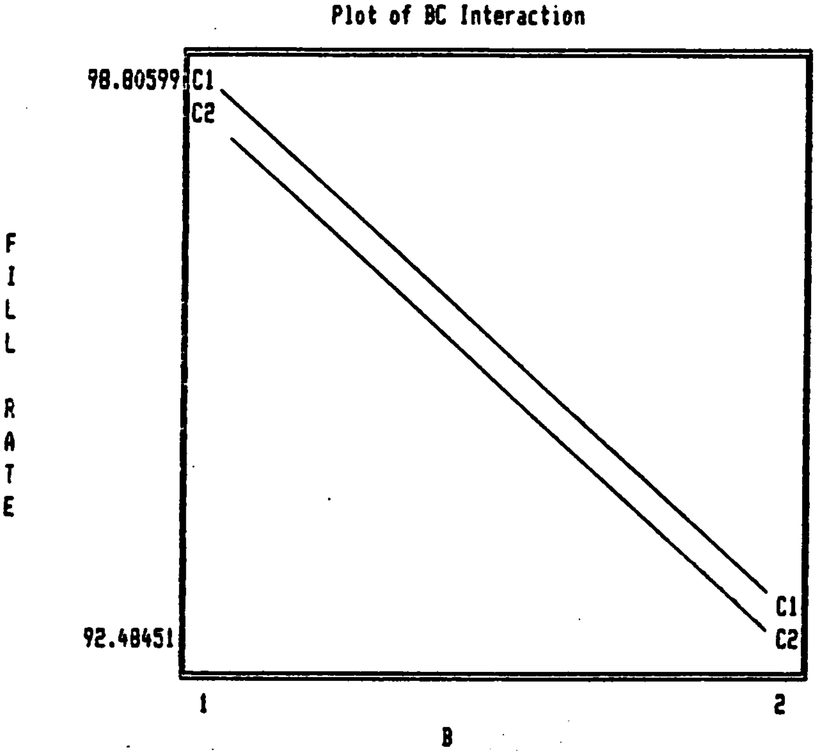

Plot of AC Interaction

FIGURE 9
MAIN EFFECT INTERACTIONS FOR
PERCENT ORDERS FILLED



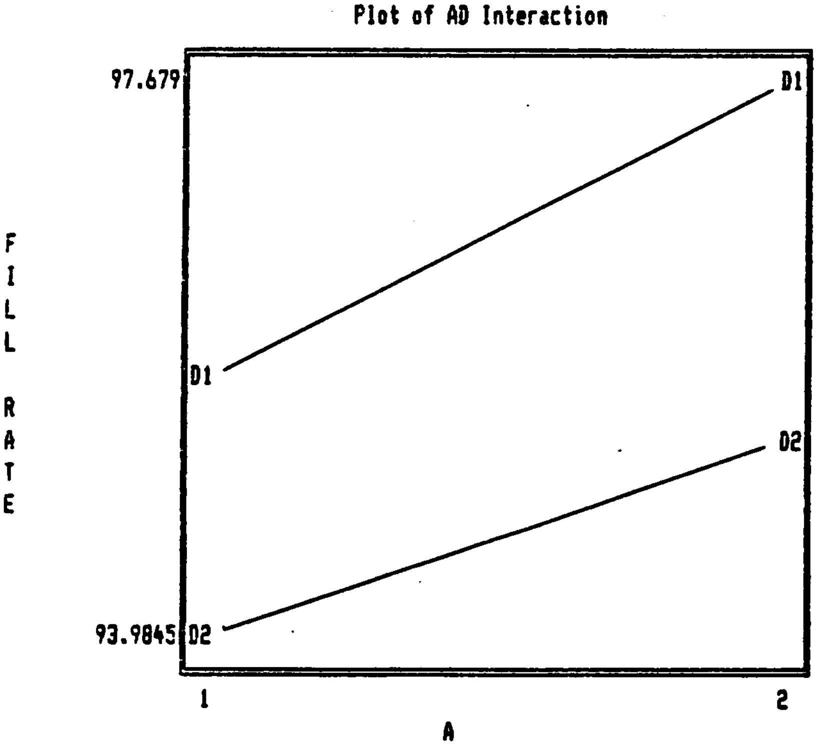


FIGURE 9 (continued)

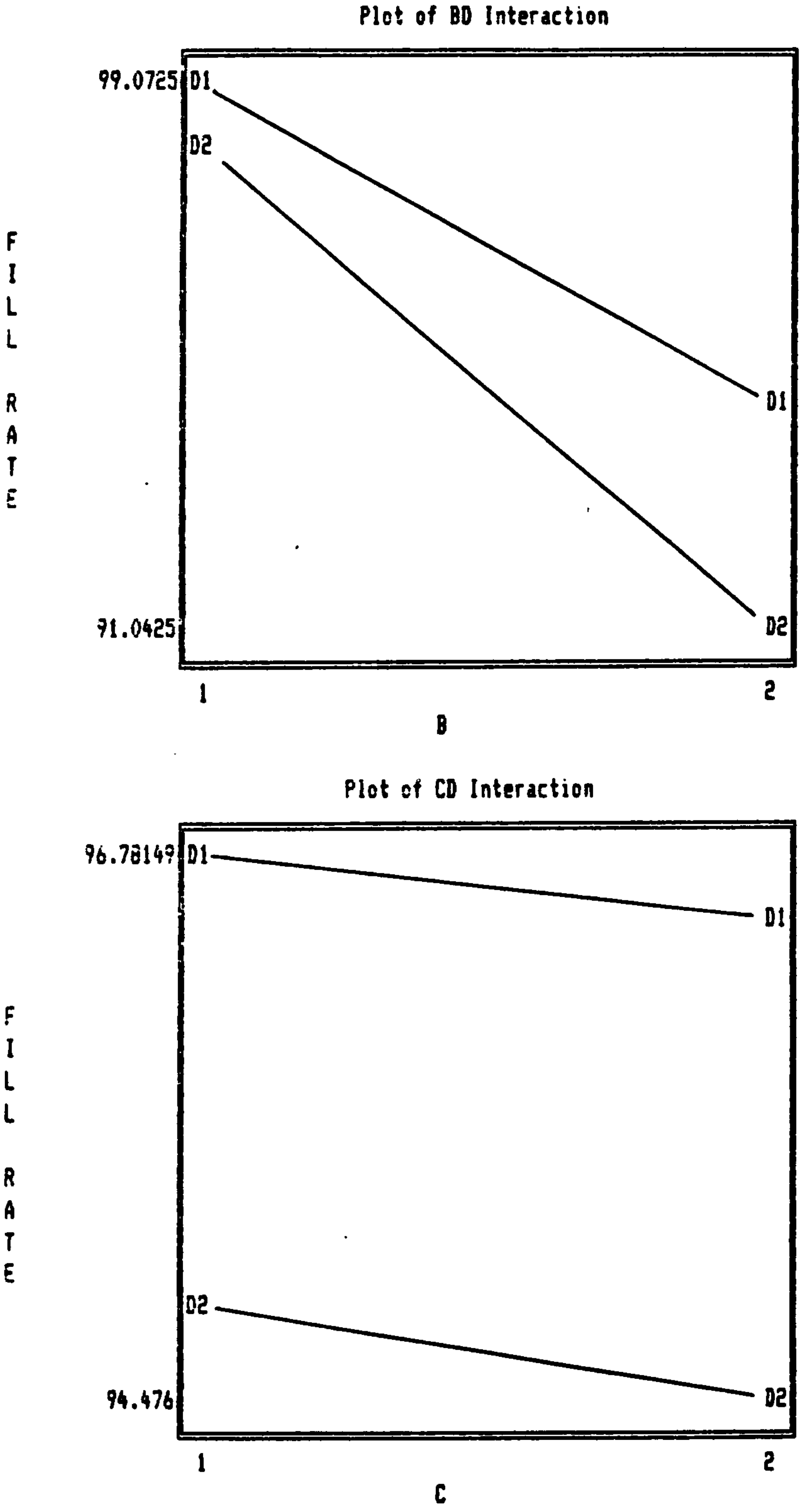


FIGURE 9 (continued)

DEPENDENT VARIABLE 1 - PROFIT

Table 13 indicates significant main effects for (A) Materials Management JIT, (C) Materials Management Operational Uncertainty, and for (D) Demand Uncertainty. The main effect for (B) Physical Distribution JIT was not significant, but several of the interactions involving it were significant. This suggests that the variable is a contributor but the main effect is canceled out.

Interactions which cross are of concern because they complicate understanding factor relationships with the response variable. Severe interactions which cross near the center of the plot result in a cancelling of main effects referred to as masking. Masking could result in an incorrect acceptance of the null hypothesis of no factor effect. Plots which do not cross (even if extended) are parallel and represent that the factors do not interact.

Of the interactions indicated in Figure 6, only AB and BC cross within the domain of the factor levels. Since both cross relatively close to the domain boundary, little effect will need to be considered.

DEPENDENT VARIABLE 2 - ORDER CYCLE TIME

Table 14 indicates significant main effects for (A) Materials Management JIT, and (C) Materials Management Uncertainty. (B) Physical Distribution JIT and (D) Demand Uncertainty were not significant, but again, several of their interactions were.

A review of Figure 7 indicates severe interactions occurring in AC, AD, BD, and CD. Respectfully, these interactions represent:

> materials management JIT with materials management uncertainty
> materials management JIT with demand uncertainty
> physical distribution JIT with demand uncertainty
> materials management uncertainty with demand uncertainty.

The presence of multiple severe interaction make it difficult to fully understand how factors are affecting the group means.

As discussed in chapter III, two factors interact if the difference in mean responses for two levels of one factor are not constant across levels of the second factor. This could indicate that the factors are not independent or not additive as the assumed model suggests.

It is known that the factors have been operationalized independently in the GPM model, therefore the possibility that there is some amount of non-additivity must be considered. In this case, the factors are said to potentiate or antagonize one another (depending on if the effect is positively or negatively synergistic) when both are present.

The interactions found in the independent variables acting on the order cycle time response were not unexpected. From the plot of the AC interaction in Figure 7 it can be seen that for the low materials management uncertainty condition there was little order cycle time change across the with or without conditions of materials management JIT. However, for the high materials management uncertainty condition there was a large change in order cycle time across the with or without conditions of materials management JIT. This supports the commonly held contention that any system uncertainty would be very detrimental to the performance of JIT. Of the four order cycle time interactions, the first three were similar interactions between system uncertainty and JIT.

The fourth interaction was between the two types of system uncertainty. Plot CD in Figure 7 indicates that under the low demand uncertainty condition order cycle time was much less affected by going from low to high materials management uncertainty, than under the high demand uncertainty condition. The specifics of this negative synergistic effect will be tested by hypothesis 11.

DEPENDENT VARIABLE 3 - STANDARD DEVIATION OF THE ORDER CYCLE TIME

Table 15 indicates significant main effects for all of the four independent variables. Except for two, the interactions were also all significant. Severe interaction, represented in Figure 8, was limited to AB:

physical distribution JIT with materials management JIT

The AB plot in Figure 8 indicates that under the condition of without physical distribution JIT, changing from with to without materials management JIT had less effect on the variability of the order cycle time than under the condition of with physical distribution JIT. The specifics of this interaction will be tested by Hypothesis 10.

DEPENDENT VARIABLE 4 - PERCENT ORDERS FILLED

Table 16 indicates that all of the independent variable main effects and all but four of their interactions were significant. Figure 9 suggests that only the severe interaction was AC:

materials management JIT with materials management uncertainty

This was an interaction of system uncertainty and JIT, similar to the first three interactions discussed in order cycle time. Plot AC of Figure 9 indicates that under a low materials management uncertainty condition, going from with to without materials management JIT has less effect on percent orders filled than under a high materials management uncertainty condition. Again supporting the contention that JIT can not handle system uncertainty. The significance of specific comparisons will be tested by the research hypotheses.

ANACOVA ADJUSTED MEANS AND ANOVA MEANS

As described in the initial experimental results section, the analysis followed a two step process: 1) analysis of variance, and 2) multiple comparisons of cell means procedures. The analysis of variance (covariance for the profit variable) has rejected the null hypothesis of equal cell means and has indicated that the main effects and interactions of interest are significant. Multiple comparison procedures can now be applied to the cell means to determine how they differ and to test the research hypotheses.

Table 17 reflects the adjusted means for the sixteen cell analysis of covariance experimental design and the non-adjusted means for the response variables which were analyzed with analysis of variance. This is the data which will be used to test the research hypotheses.

Table 17

CELL MEANS
(experimental results)

			with mat'l mgt JIT		without mat'l mgt JIT	
			low demand uncert	high demand uncert	low demand uncert	high demand uncert
with pd JIT	low mat'l mgt uncert	PR	$451,300	$445,151	$473,155	$468,663
		OCT	6.058	6.121	5.986	6.043
		SD	0.557	0.725	0.215	0.255
		PF	98.996	98.376	99.444	98.438
	high mat'l mgt uncert	PR	$448,768	$443,459	$468,950	$467,147
		OCT	6.173	6.222	6.028	6.063
		SD	0.745	0.928	0.238	0.323
		PF	98.647	98.087	99.233	98.311
without pd JIT	low mat'l mgt uncert	PR	$473,941	$449,229	$461,810	$455,906
		OCT	6.028	6.117	6.316	6.018
		SD	0.159	0.350	0.285	0.250
		PF	94.770	90.137	93.946	92.527
	high mat'l mgt uncert	PR	$444,733	$438,815	$481,360	$448,531
		OCT	6.219	6.245	6.026	6.086
		SD	0.735	0.760	0.157	0.638
		PF	90.339	89.338	98.093	92.168

PR = MEAN PROFIT IN DOLLARS
OCT = MEAN ORDER CYCLE TIME IN DAYS
SD = MEAN STANDARD DEVIATION OF ORDER CYCLE TIME IN DAYS
PF = MEAN PERCENT CUSTOMER ORDERS FILLED

POST ANOVA (ANACOVA) STATISTICAL TEST METHODS

Comparisons of cell means were required to test the research hypotheses. In the majority of cases these comparisons involved two groups of multiple means. Proper application of statistical methods suggests that different procedures are necessary for the comparison of: 1) two cell means and 2) two groups of multiple means.

"Fisher's Least Significant Differences (LSD)," can be used to compare two cell means (Ott 1984). However, according to Lentner and Bishop (1986), such methods are only useful for basic comparisons of mean pairs. For more general comparisons, a contrast procedure proposed by Scheffe can be used to detect significant differences between any combination of population means. These two statistical methods were used in post ANOVA (ANACOVA) comparisons of cell means.

Scheffe's S Method of Multiple Comparisons

The test procedure will follow the format outlined by Ott (1984) for Scheffe's S Method of Multiple Comparisons:

1. Any linear comparison among t population means can be represented by a linear contrast of cell means whose a_i coefficients sum to zero. For example:
   $I = 1/2\ (\mu_1 + \mu_2) - 1/3\ (\mu_3 + \mu_4 + \mu_5)$.

2. The null hypothesis for this example is that the mean of $(\mu_1 + \mu_2)$ is not significantly different from the mean of $(\mu_3 + \mu_4 + \mu_5)$.
   H_0 : I = 0, against the alternative,
   H_a : I $\neq$ 0

3. The test statistic for the example would be the estimate of the I contrast which is formed by the cell means and their coefficients.
   $\hat{I} = a_1 \bar{y}_1 + a_2 \bar{y}_2 - a_3 \bar{y}_3 - a_4 \bar{y}_4 - a_5 \bar{y}_5$

4. The test statistic is compared to the calculated value of S (from which the S method gets its name).
   $S = \sqrt{\hat{V}} \ \sqrt{(t-1) F_{\alpha}, df1, df2}$
   where

   the variance (V) of the linear contrast estimate $(\hat{I})$ can be estimated from:

   $\hat{V} = \text{MSE} \ (a_1^2/n_1 + a_2^2/n_2 + \ldots)$.

   where

   MSE = mean square error within, from the ANACOVA or ANOVA table.
   t = the total number of population means.
   $F_{\alpha}, df1, df2$ = is the upper tail critical value of the F distribution.
   df1 = t - 1
   df2 = degrees of freedom of MSE within.
   μ_i = population means.
   $\bar{y}_i$ = sample means.

5. For a specific value of α, H_0 is rejected if $|\hat{I}| > S$. In this study the α value for all of the hypothesis tests will be 0.05.

6. The error rate is a experiment-wise error rate. That is, considering all possible contrasts, the probability of one or more being falsely declared significant is designated by the value of α.

Fisher's Least Significant Differences (LSD) Method

While Scheffe's method is conservative and well suited to the comparison of a number of general contrasts, Ott (1984) suggests that the method should not be used for pair-wise comparisons. For those few hypotheses which require pair-wise comparisons, Fisher's Least Significant Differences (LSD) method will be applied. Following the outline suggested by Lentner and Bishop (1986) the procedure for this method will be:

1. The null hypothesis is represented by:
   $H_0 : I = \mu_1 - \mu_2 = 0$
2. The test statistic is represented by the contrast estimate:
   $\hat{I} = \bar{y}1 - \bar{y}2$
3. The test statistic is compared to the value of the LSD term.
   $\text{LSD} = [(\text{Sd})(R_2, \alpha, df)]/ \sqrt{2}$
   where
   Sd = standard deviation of the difference in sample means.
   $\text{Sd} = \sqrt{MSE(1/r_1 + 1/r_2)}$
   r_1 = the number of observations in cell 1
   r_2 = the number of observations in cell 2
   R_2, α, df = the Studentized range value for order 2, $\alpha = 0.05$, and df = the degrees of freedom from the MSE.
4. Reject the null hypothesis if the absolute difference of the observed means exceeds the value of LSD.

The investigation of the majority of hypotheses in this study will require the comparison of more than one set of cell means. The format of each analysis will be to identify the cell groups involved, rank order their means, indicate which differences are significantly different, and finally indicate the support or non-support of the main hypothesis. With the means rank ordered, and an indication of which comparisons between them are significant, it should be possible to effectively visualize the results of the test series.

RESEARCH HYPOTHESES TEST RESULTS

Throughout this section the following convention was followed:

1. $\alpha = 0.05$ for all significance tests.

2. Where the mean of <u>cells</u> is reported, Scheffe's Method has been applied.
3. Where the mean of a <u>cell</u> is reported, Fisher's Method has been applied.
4. The units of the mean values of the response variables are as follows: profit in dollars, order cycle time in days, standard deviation of the order cycle time in days, and percent customer orders filled as a percent.
5. The use of the terms "positive effect" and "negative effect" in the wording of the research hypotheses are to be interpreted as "favorable" and "non-favorable", rather than an indication of the sign (+/-) of the value of the effect. Thus, examples of positive effects would be; greater profit, lower order cycle time, lower standard deviation of the order cycle time, and higher percent customer orders filled.

H_1 The introduction of JIT in any configuration will have a significant positive effect on profit across all treatments.

Mean of
cells without JIT .... \$461,902 A

mean of
cells with JIT .... \$456,103 B

The difference between A and B was not significant. The H1 hypothesis was not supported. Only the support or non-support of the hypothesis will be reported here. The discussion of each result will be reserved for the Chapter V. It is noted however, that the rank order of the results, (if significant) would have indicated a negative profit effect for JIT. The reverse of what was expected.

H_2 System-wide (both sides) JIT will produce the greatest positive effect on profit, followed by materials management side and then physical distribution side (all under low uncertainty).

Mean of
cell with only mat'l mgt JIT .... \$473,941 A

Mean of
cell with only phy dist JIT .... \$473,155 B

Mean of
cell without JIT .... $461,810 C

Mean of
cell with system-wide JIT .... $451,300 D

D - C significant, but in the wrong direction.

B - C significant

A - C significant

D - B significant, but in the wrong direction.

D - A significant, but in the wrong direction.

A - B not significant

The H2 hypothesis was not supported. Materials management JIT and physical distribution JIT both had significant positive effects on profit, but their values were not significantly different from each other. System-wide JIT had a significant negative effect on profit.

> H_3 With system-wide JIT, profit will be negatively impacted more by high materials management operational uncertainty than by high demand uncertainty.

Mean of
cells with low demand uncertainty ...$450,034 A

Mean of
cells with low mat'l mgt uncertainty .$448,225 B

Mean of
cells with high mat'l mgt uncertainty $446,113 C

Mean of
cells with high demand uncertainty ...$444,305 D

A - D not significant

B - C not significant

D - C not significant

A - B not significant

The H3 hypothesis is not supported due to a lack of significant differences for the profit response within the system-wide JIT quadrant.

> H_4 System-wide JIT will be negatively impacted in profit more by high materials management uncertainty and demand uncertainty than a non-JIT system.

Mean of
cell without JIT, with low mat'l mgt
uncert, and low demand uncert ....$461,810 A

Mean of
cell with system-wide JIT, low mat'l mgt
uncert, and low demand uncert ....$451,300 B

Mean of
cell without JIT, but with high mat'l mgt
uncert, and high demand uncert ...... $448,531 C

Mean of
cell with system-wide JIT, high mat'l mgt
uncert, and high demand uncert ...... $443,459 D

A - B significant

C - D not significant

B - C not significant

D - B significant

C - A significant

Hypothesis H4 is not supported. While high uncertainty affected both the system-wide JIT and the non-JIT cells, the magnitude of the affect on the non-JIT was greater. This is shown by the low uncertainty non-JIT group profit response being significantly greater than the low uncertainty system-wide JIT group profit, while the high uncertainty responses were not significantly different. The cell means did fall in a rank order which would have supported the hypothesis had their differences been significant.

> H_5 High demand uncertainty does not result in lower profit as compared to low demand uncertainty.
>
> Mean of
> cells with low demand uncertainty ... $463,002 A
>
> Mean of
> cells with high demand uncertainty .. $452,113 B
>
> Mean of cells
> W/O JIT & low demand uncertainty .... $471,585 C
>
> Mean of cells
> W/O JIT & high demand uncertainty ... $452,218 D
>
> A - B significant
>
> C - D significant

The hypothesis H5 is not supported. High uncertainty results in significantly less profit, both across all cells and across only non-JIT cells.

> H_6 The presence of both materials management JIT and physical distribution JIT will produce a positive synergistic effect on profit.
>
> Mean of
> cells with physical distribution JIT. $469,479 A
>
> Mean of
> cells without JIT .... $461,902 B
>
> Mean of
> cells with mat'l mgt JIT only .... $451,680 C
>
> Mean of

cells with system-wide JIT .... $447,169 D

D - B significant

A - B not significant

C - B significant

D - A significant

D - C not significant

A - C significant

The hypothesis H6 is not supported. The positive synergistic effect of system-wide JIT was not indicated. Physical distribution JIT did not result in a significant positive profit effect as compared to non-JIT cells. Materials management JIT and system-wide JIT resulted in significant negative profit responses, that were not significantly different from each other. Not only was the hypothesis not supported, but the effect was in the wrong direction. If D - C had proven significant, the results would have indicated a negative synergistic effect on profit (i.e., the $14,733 difference between the base line mean of cells without JIT and the mean of cells with system-wide JIT would have been greater than the sum of the physical distribution JIT effect (-$7,577) and the effect of materials management JIT (+$10,222).

> H_7 The presence of both high materials management operational uncertainty and high demand uncertainty will produce a negative synergistic effect on profit.

Mean of
cells with both low mat'ls mgt
uncert and low demand uncert........ $465,052 A

Mean of
cells with high mat'ls mgt
uncert and low demand uncert........ $460,953 B

Mean of cells with high demand uncert and low mat'ls mgt uncert....	$454,737 C
Mean of cells with both high mat'ls mgt uncert and high demand uncert	$449,488 D

D - A significant

B - A not significant

C - A significant

D - C not significant

The hypothesis H7 was not supported. The means fell in the correct rank order to support the hypothesis, but the non-significance of the D - C comparison suggests that the effect of high demand uncertainty alone was not significantly different compared to the effect when both uncertainties were present. If the D - C means had been shown to be significantly different, the results would have supported the negative synergistic effect posited in the hypothesis. Using the mean of the cells with both uncertainties low as a base line, the effect of high materials uncertainty alone was -$4,099. The effect of high demand uncertainty alone was -$10,315. The sum of these two effects is exceeded by the effect of the two uncertainties together -$15,564.

H_8 The introduction of JIT in any configuration will not have a significant positive effect on service across all treatments.

<u>Order Cycle Time (days)</u>

Mean of cells with JIT	6.108 A

Mean of
cells without JIT .... 6.112 B

A - B not significant

Standard Deviation of Order Cycle Time (days)

Mean of
cells with JIT .... 0.4992 A

Mean of
cells without JIT .... 0.3325 B

A - B significant

Percent (customer) Orders Filled

Mean of
cells with JIT .... 96.1738 A

Mean of
cells without JIT .... 94.1835 B

A - B significant

The hypothesis H8 was supported for order cycle time only. The introduction of JIT had a significant negative effect on the standard deviation of the order cycle time and a significant positive effect on percent orders filled.

H_9 With system-wide JIT, service will be negatively impacted more by high materials management operational uncertainty than by high demand uncertainty.

Order Cycle Time (days)

Mean of
cell with high mat'ls mgt uncertainty
and low demand uncertainty .... 6.173 A

Mean of
cell with high demand uncertainty
and low mat'ls mgt uncertainty ...... 6.121 B

Mean of
cell with low mat'ls mgt uncertainty
and low demand uncertainty .... 6.058 C

A - C significant

B - C not significant

A - B not significant

Therefore, H9 is supported for order cycle time.

Standard Deviation of Order Cycle Time (days)

Mean of
cell with high mat'ls mgt uncertainty
and low demand uncertainty .... 0.745 A

Mean of
cell with high demand uncertainty
and low mat'ls mgt uncertainty ...... 0.725 B

Mean of
cell with low mat'ls mgt uncertainty
and low demand uncertainty .... 0.557 C

A - C significant

B - C significant

A - B not significant

Therefore, H9 is not supported for standard deviation of order cycle time. Both high materials management uncertainty and high demand uncertainty have significant negative effects, but they are not significantly different from each other. The cell means did fall in a rank order that would have supported the hypothesis had their differences been significant.

Percent (customer) Orders Filled

Mean of cell with high demand uncertainty and low mat'ls mgt uncertainty	98.376 A
Mean of cell with high mat'ls mgt uncertainty and low demand uncertainty	98.647 B
Mean of cell with low mat'ls mgt uncertainty and low demand uncertainty	98.966 C

A - C significant

B - C not significant

A - B not significant

The hypothesis H9 was not supported for percent orders filled. Only demand uncertainty had a significant negative impact.

H_{10} The presence of both materials management JIT and physical distribution JIT will not produce a positive synergistic effect on service.

Order Cycle Time (days)

Mean of cells with only mat'l mgt JIT	6.152	A
Mean of cells with system-wide JIT	6.144	B
Mean of cells without JIT	6.112	C
Mean of cells with only phy dist JIT	6.030	D

A - C not significant

B - C not significant

D - C not significant

D - A not significant

Since the effects are not significant, H10 is supported for order cycle time. If the cell mean differences had been significant, the rank order would still not have supported the existence of the synergistic effect.

Standard Deviation of Order Cycle Time (days)

Mean of cells with system-wide JIT	0.739	A
Mean of cells with only mat'l mgt JIT........	0.501	B
Mean of cells without JIT	0.333	C

Mean of
cells with only phy dist JIT......... 0.258 D

A - B significant

A - C significant

B - C significant

D - C not significant

D - B significant

System-wide JIT resulted in a larger mean variability in the standard deviation and was significantly different than the means of materials management JIT and physical distribution JIT taken singularly. Since the hypothesis posited the lack of a positive synergistic effect, this result of an apparent negative synergistic effect supports it.

Taking the mean of cells without JIT as a base line, the effect of physical distribution only JIT was -.075 (not significantly different from the 0 baseline). The effect of materials management only JIT was +.168. Their sum did not equal the effect of system-wide JIT which equaled +.406. This larger value of variability is not a positive (favorable) effect since this is one of the variables for which a positive effect has been defined as a lower value.

H10 is supported for standard deviation of order cycle time.

Percent (customer) Orders Filled

Mean of
cells with only mat'l mgt JIT....... 91.146 A

Mean of
cells without JIT .... 94.184 B

Mean of
cells with system-wide JIT .... 98.519 C

Mean of
cells with only phy dist JIT .... 98.857 D

A - B significant

C - B significant

D - B significant

D - A significant

The hypothesis H10 was supported for all of the service response variables. In the test on order cycle time none of the cell groups compared had significant effects. In the test on standard deviation of the order cycle time the presence of both physical distribution JIT and materials management JIT seemed to have a negative synergistic effect. For percent orders filled the physical distribution JIT had a positive effect while the materials management JIT produced a negative effect. Since system-wide JIT did not yield the greatest positive effect, the possibility of a synergistic effect was ruled out.

H_{11} The presence of both high materials management operational uncertainty and high demand uncertainty will produce a negative synergistic effect on service.

<u>Order Cycle Time (days)</u>

Mean of
cells with high mat'ls mgt uncertainty
and high demand uncertainty .... 6.154 A

Mean of

cells with high mat'ls mgt uncertainty
and low demand uncertainty .... 6.112 B

Mean of
cells with low mat'ls mgt uncertainty
and low demand uncertainty .... 6.097 C

Mean of
cells with high demand uncertainty and
low mat'ls mgt uncertainty .... 6.075 D

A - C not significant

B - C not significant

D - C not significant

A - D not significant

Since the effects are not significant, H11 is not supported. Had the cell mean differences been significant, the groups were in a rank order to support the hypothesis. Using the "both uncertainties low" cell mean as a base line, the high demand effect alone was -.022. High materials management uncertainty alone produced a +.015 effect. The effect of both uncertainties was greater than the sum of the uncertainties taken singularly at +.057. Since a greater order cycle is unfavorable according to the convention established for the research hypotheses, this would have been a negative synergistic effect.

Standard Deviation of Order Cycle Time (days)

Mean of
cells with high mat'ls mgt uncertainty
and high demand uncertainty .... 0.662 A

Mean of
cells with high mat'ls mgt uncertainty
and low demand uncertainty .... 0.469 B

Mean of
cells with high demand uncertainty and
low mat'ls mgt uncertainty .... 0.395 C

Mean of
cells with low mat'ls mgt uncertainty
and low demand uncertainty .... 0.304 D

A - B significant

A - D significant

B - D significant

C - D not significant

C - B not significant

H11 is supported for standard deviation of order cycle time. With the "both uncertainty low" treatment as a base line, high demand uncertainty alone produced a +.091 effect (not significantly different than zero). High materials management uncertainty alone produced a + .165 effect. The effect of the treatment which contained both high uncertainties (+.358) exceeded the sum of the two singular applications. Since a higher variability is unfavorable, this represents a negative synergistic reaction.

Percent (customer) Orders Filled

Mean of
cells with high mat'ls mgt uncertainty
and high demand uncertainty .... 94.476 A

Mean of
cells with high demand uncertainty
and low mat'ls mgt uncertainty ..... 94.870 B

Mean of
cells with high mat'ls mgt uncertainty
and low demand uncertainty .... 96.578 C

Mean of
cells with low mat'ls mgt uncertainty
and low demand uncertainty .... 96.781 D

A - D significant

B - D significant

C - D not significant

A - B not significant

B - C not significant

Once again the cell means fell in a rank order which could support a negative synergistic reaction, but significance between means was lacking. Using the "both uncertainty low" as a base line, the high materials management uncertainty effect alone was -.203. The effect of high demand uncertainty alone was -1.911. The effect of the treatment with both high uncertainties present exceeded the sum of the two singular applications with an effect equal to -2.305.

The hypothesis H11 was only supported for standard deviation of the order cycle time. For standard deviation of order cycle time the negative effects of both types of uncertainty present at the same time were greater than the sum of their individual effects. The test involving order cycle time did not produce significant differences. The test involving percent orders filled did not indicate a significant difference between the presence of both high uncertainty conditions verses high demand uncertainty alone, thus ruling out significant synergistic interaction.

CHAPTER V

DISCUSSION AND CONCLUSIONS

This chapter examines the experimental results as they relate to the study's objectives, conceptual framework, and the previous research from which the research hypotheses were developed. Following the discussion of the hypotheses, overall implications and conclusions which can be inferred from the study will be discussed. In the final sections, the limitations of the study will be considered and areas for future research will be suggested.

DISCUSSION OF HYPOTHESES

The objective of this research was to "empirically explore the performance of JIT alternative configurations from a total system perspective". That is, recognizing that the internal functions of a channel system are a complex networking of interdependent and intradependent factors. The recognition that alternative inventory flow policies are imbedded within time dependent complex larger systems, supported the decision to utilize a temporal total systems approach as suggested by General Systems Theory. The channel system was simulated by way of the

Global Planning Model software which allowed subsystems to interact and produced total system performance measures as output.

Performance measures of profitability and service were collected under alternative JIT configurations and under alternative uncertainty conditions. With this data and appropriate statistical hypothesis testing procedures, insight into the nature of JIT inventory flow was gained.

The support or non-support of each of the research hypotheses was based on statistical significance at $\alpha = 0.05$. While a larger value could be argued in this type of exploratory research, calculations indicated that an α unacceptably greater than 0.1 would have been required to appreciably increase the number of hypotheses supported.

HYPOTHESIS 1

> The introduction of JIT in any configuration will have a significant positive effect on profit across all treatments. NOT SUPPORTED

As stated by Monden (1983) the most important goal of the JIT system is cost reduction. Although JIT provides cost reductions due to reduced inventory carrying costs, the non-significant results of this hypothesis indicate that the extent of savings may be situation specific. That is, if there is an investment required to implement JIT, the payback will not be automatic. If there is a payback at all, it will depend on the specific nature of demand volume, product value, the risk of carrying inventory, the cost of money and the extent of operational and demand uncertainty inherent in the environment.

The study involved alternatives of: 1) JIT receipt of low value raw material, 2) value added production on an as demanded basis, and 3) JIT shipment of finished goods. The results suggest that JIT does not always have a positive profit impact. With interactions taking place with other factors and subsystems it is possible to create conditions where JIT would be detrimental to profit performance.

JIT, however, does not normally function in isolation from such factors as significant supplier price concessions, operational savings from significant supplier quality improvements, and a wide range of benefits from supportive worker attitudes. While these factors cannot be reflected in a simulation without the appearance of "fixing" the results, they should be considered in interpreting implications of the findings. Whether these issues are basic to, or separate from JIT is a question of definition and philosophy.

For managers contemplating adoption of system-wide JIT or one sided (physical distribution or materials management) JIT systems, the nonsupport of this hypothesis suggests caution. Since the test was conducted across all treatments, there is an indication that JIT may not be able to operate efficiently under conditions of operational and environmental uncertainty. Additional research is needed to delineate the conditions under which various applications of JIT can function without negative profit effects.

HYPOTHESIS 2

> System-wide JIT will produce the greatest positive effect on profit, followed by materials management JIT and then physical distribution JIT (all under low uncertainty). NOT SUPPORTED

Under the conditions of low material management operational uncertainty and low demand uncertainty, the factors of physical distribution JIT and materials management JIT both had individual significant positive affects on profitability. The results of the two JIT alternatives, however, were not significantly different and they could not be ranked by performance. This alone is enough to reject Hypothesis 2.

A potentially important finding was that taken together (in system-wide JIT), the positive results of the two subsystems (MM-JIT and PD-JIT) produced a significant negative interaction. This result was not expected, particularly under conditions of low uncertainty. While it was recognized that no previous research compared system-wide JIT to JIT only on the materials management side or to JIT only on the physical distribution side it was expected that the GST tenet that "the whole is more than the collection of its parts" (Klir 1978) would suggest a positive result.

It should also be recalled that the system being simulated should be viewed as a multiechelon company or alternatively a supplier-manufacturer-customer channel. The benefits that are accruing somewhere in the channel under materials management JIT are not necessarily in the same location as the benefits accruing under physical distribution JIT.

The full impact of this finding will be reserved until the similar service hypothesis results are discussed. A fuller view of system-wide JIT across all dependent variables will then be available.

For managers of multi-echelon firms the non-support of this hypothesis suggests that selected application of JIT on material flows between echelons may be superior to a system-wide adoption. With a lack of empirical JIT research and the majority of anecdotal support for JIT considering only the effect on the focal organization, this evidence of a negative profit impact with system-wide JIT could be a major insight into the nature of JIT. The issue deserves additional research.

HYPOTHESIS 3

> With system-wide JIT, profit will be negatively impacted more by high materials management operational uncertainty than by high demand uncertainty. NOT SUPPORTED

In the system-wide JIT profit quadrant there were no significant profit differences between levels of materials management operational uncertainty, levels of demand uncertainty or between each other.

A common criticism of JIT is that it is sensitive to uncertainty, particularly demand uncertainty. Monden (1983) described Toyota reassigning workloads when demand changed in excess of 20%. The simulation model in this study was not allowed to make such changes due mainly to the fact that U.S. JIT applications do not report this capability. Often workers are not cross trained, union rules would not permit, and U.S.

managers would not like to see the low machine utilization rates which would be inherent in the one-operator-several-machine work assignments Toyota uses to respond to reduced demand.

Neither of the uncertainty conditions produced a significant profit difference within the system-wide JIT quadrant. If profit were the only dependent variable or if system-wide JIT represented the entire treatment domain, the operationalization of uncertainty would likely be considered to have failed. Since the operationalization did impact the results of other treatments and variables, further consideration of the nature of system-wide JIT, uncertainty, and the profit variable is required.

Profit is earned by units shipped. Lower than average demand could result in fewer units shipped and result in lower profit. Higher than average demand should result in more units shipped except when stockouts result in lost orders.

System-wide JIT would be very responsive at replenishing the small inventory amounts consumed inbetween supplier shipments. If this capability could minimize the impact of the percentage of higher than average requirements under high demand uncertainly, the only negative impact would be the amount lost under low demand uncertainty. Since the average demand was not manipulated across treatments (only the standard deviation of demand), much of this would average out. A portion of the effect of the total demand which did not average out was removed by the regression adjustment of the profit cell means by the ANACOVA statistical procedure. The low demand profit impact could be offset by the high demand conditions occurring throughout the simulation. From this perspective, demand uncertainty was expected to have the lesser impact in the hypothesis.

Materials management operational uncertainty was expected to have a major impact on JIT. Large variations in supplier product availability would be expected to impact even a conventional system which is considered to be less sensitive. There could be something in the nature of JIT that counteracts its sensitivity to this type of uncertainty.

Materials management operational uncertainty suggests supply interruptions if inventory levels are not sufficient to cover production. In a conventional system this situation generates images of workers being idle, non-productive, or being sent home.

Under JIT, inventory levels are minimized rather than machine utilizations maximized. Faced with low demand or in this case low supply, JIT workers will perform other parts of their job assignments, (e.g., maintenance, quality circles, or quick changeovers to produce other products). While Toyota may dull the impact of materials management or demand uncertainty in this manner, the capability was not programmed into the simulation. As discussed earlier, it would not be typical of U.S. JIT applications and it would appear to be "fixing" the model in JIT's favor.

Returning to why there was no significant profit impact by uncertainty variations. Two reasons stand out. First, only the high demand uncertainty condition likely had many lost orders. With the mean not manipulated in either demand nor materials management uncertainty, other conditions were just postponement of profit rather than losses. By the end of the simulation, only the effect of lost sales from high demand uncertainty stockouts and the few in process orders left in the system would appear as lost profit. Second, the profit reported represents channel profitability. Since the channel's profit performance is the sum of the operational echelons present, the costs of some uncertainties could conceivably be offset by savings at other locations. The effect of uncertainty on individual units should be the topic of future research, which may find individual effects to be as suggested by this hypothesis.

For managers the non-support of this hypothesis suggests that they must be fully aware of the levels of demand uncertainty the system is likely to encounter before adopting JIT. There is some evidence that a JIT system can be quite sensitive to appreciable levels of demand uncertainty.

HYPOTHESIS 4

System-wide JIT will be negatively impacted in profit more by high materials management uncertainty and demand uncertainty than a non-JIT system. NOT SUPPORTED

The results suggest that the without JIT quadrant is impacted more by high levels of demand and materials management operational uncertainty than the system-wide JIT quadrant. This is the opposite of the effect direction expected in the hypothesis.

The without JIT system, being less demand and usage responsive, would cover high certainty by increasing inventories. The costs involved in carrying additional inventory apparently exceeded the value of the lost orders when JIT stocked out. As discussed under the last hypothesis, a Toyota style system-wide JIT system would be expected to handle uncertainty and to produce results as this simulation actually did. The JIT system provided an advantage in superior responsiveness to the changing conditions brought about by uncertainty in the environment. If JIT could not handle the uncertainties inherent to a manufacturing environment it would not be practical for Americans or Japanese.

The implication of the non-support of the hypothesis for managers is that while high environmental uncertainty has a negative profit impact on JIT systems (from hypothesis 3), the negative impact on a non-JIT system under the same conditions may be greater. However, the difference may be produced from the profit value of the lost orders with JIT, versus the cost of additional inventory for non-JIT. While the lost orders with JIT may have a lesser profit effect, the manager must also consider the possible long term customer service effect of the stockouts. Under these conditions the profit advantage of JIT would only continue to accrue if customers continued to order even though stockouts are occurring. This may not be a problem if the market is characterized by oligopoly or a demand that continuously exceeds supply.

HYPOTHESIS 5

> High demand uncertainty does not result in lower profit as compared to low demand uncertainty. NOT SUPPORTED

High demand uncertainty was found to generate reduced profit as compared to low demand uncertainty, both across all cells and across all without JIT cells. The results require little explanation. Business people and researchers have never considered high demand uncertainty to be a desirable market characteristic. The fact that these results contradict a previous published study suggests that the matter has not been settled. The Speh and Wagenheim (1978) results of no demand uncertainty effect are particularly important since the model utilized was an early predecessor of the GPM model used for this study. In the Speh and Wagenheim study the data was derived from one simulated ninety day run under each treatment. In the GPM model of the present study, the data was derived from ten 242 day runs under each of sixteen treatment conditions. The total time simulated was therefore, 160 working years. The fact that the findings differ reinforces the need for additional study.

For managers the non-support of this hypothesis reinforces the cautions presented under Hypotheses 3 and 4, and adds to a fuller understanding of the negative impact of environmental uncertainty. Control of demand variability should be an important strategic consideration. In some situations marketers can influence demand variability by the timing of promotional efforts, price reductions for long term consistent demand, and the choice of products and markets.

HYPOTHESIS 6

> The presence of both materials management JIT and physical distribution JIT will produce a positive synergistic effect on profit. NOT SUPPORTED

Interactions in this type of system have not been explored. In Figure 6 several interactions are depicted. Speh (1974) stated that interactions were not an important aspect of that research, "the nature of the experimental variables precludes a meaningful interpretation of the interaction effects." The results of the present study suggest interaction effects of a complex nature which may be important to understand.

Physical distribution JIT alone had an non-significant effect on profit. Materials management JIT alone had an unexpected significant negative effect. Both together (System-wide JIT) did not produce a significantly different result from materials management JIT alone (i.e., still negative). Again the conventional thinking about JIT is placed in question pending additional research.

For managers the non-support of this hypothesis is another bit of evidence that JIT may not be advantageous across all echelons.

HYPOTHESIS 7

> The presence of both high materials management, operational uncertainty and high demand uncertainty will produce a negative synergistic effect on profit. NOT SUPPORTED

While the cell means fell in the rank order to support Hypothesis 7, the negative effect of high demand uncertainty alone was not significantly different from the negative effect of both high demand uncertainty and high materials management uncertainty together. Perhaps a study more focused on this issue could have utilized a less conservative procedure than Scheffe's for multiple comparisons of means.

Although the hypothesis was not supported, the results do not preclude support from future studies and the need for additional research is again indicated.

Managers should be particularly concerned if their firm's nature and environment presents the potential for both operational and demand uncertainty. Even though this was not supported, the rank order of the means argues for caution. While any uncertainty may be a problem, multiple uncertainties may be untenable.

HYPOTHESIS 8

> The introduction of JIT in any configuration will not have a significant positive effect on service across all treatments. SUPPORTED FOR ORDER CYCLE TIME AND STANDARD DEVIATION OF ORDER CYCLE TIME

JIT did not have a significant effect on order cycle time. This possibility was expected since the average order cycle time distribution was changed across treatments but the mean was maintained. In an actual Toyota style JIT system the order cycle time would be short as compared to a conventional system, but to program this into the model would appear to "fix" the model in JIT's favor. To make a fair and very conservative comparison, the average order cycle time was not set to be directly influenced by the JIT factors. These results indicate that it was also not indirectly influenced.

JIT across all configurations did have a significant effect on the standard deviation of order cycle time, but not a positive effect as posited. That is, a larger standard deviation of order cycle time occurred under JIT.

For percent customer orders filled, JIT had a significant positive effect. Across all JIT treatments, there was the expected tendency to carry less inventory. If the manufacturing location stocks out the order is lost and percent customer orders filled not order cycle time is affected. If the supplier location stocks out, the order is delayed and order cycle time increases. Thus, it was expected that JIT would not improve service, but would make maintaining service levels more difficult.

In the simulation, both systems were able to handle the range of uncertainties presented to them. JIT ordered different quantities every day and the conventional system automatically adjusted its EOQ. The conventional non-JIT system tended to have larger quantities backordered when it did stockout.

The JIT effect on percent customer orders filled was significantly positive (higher percentage) and not in support of Hypothesis 8.

For managers the consideration of relationships between JIT and service may be difficult to conceptualize. For many of them near 100% service levels are a prerequisite for a JIT system. Actually, this service requirement is usually a policy issue established by those whom the lower service level would negatively impact. For example, a focal organization would be likely to require high service levels from its JIT suppliers because its lines may shut down with every stockout or late delivery.

This hypothesis questions the nature of JIT to make maintaining high service levels more or less difficult than in non-JIT systems. The indication that the nature of JIT is to increase the variability of order cycle time (an unfavorable condition), but increase percent customers orders filled (a favorable condition), presents a managerial problem of control. Managerial efforts should center on negating the variability in order cycle time. Special handling and transportation methods may be required when supplier or transportation delays threaten consistent delivery performance.

HYPOTHESIS 9

> With system-wide JIT, service will be negatively impacted more by high materials management operational uncertainty than by high demand uncertainty. SUPPORTED FOR ORDER CYCLE TIME

Using the mean of the low demand uncertainty - low materials management uncertainty cells as a base line, high materials management operational uncertainty had a significant negative impact on the order cycle time response variable. High demand uncertainty did not produce a significantly different response than the mean of the base line cells. Thus, the hypothesis was supported for this element of service.

Both high materials management uncertainty and high demand uncertainty had significant negative effects on the standard deviation of order cycle time variable, but the two were not significantly different from each other. Thus, the hypothesis was not supported. As described previously, a more focused study may have justified a less conservative statistical procedure which may have found the difference significant and supported this hypothesis.

A visual scan of the system-wide JIT quadrant for percent customer orders filled indicates that unlike other quadrants, the values for this variable vary little across the four cells. Statistically there were no significant differences. While this would be typical of system-wide Toyota style JIT, nothing was programmed into the model to maintain fill rate differently under JIT. The consistent performance on this variable would seem to have been the result of the more responsive nature of the system-wide JIT across all uncertainty conditions or a lack of severe enough uncertainty to appreciably affect it.

Previous hypotheses have suggested that managers must be aware of the potential for demand uncertainty to result in a negative profit effect. The additional evidence resulting from the support of this hypothesis suggests that managers must also be cautious of the potential for materials management uncertainty to result in a negative service effect. While operational uncertainty within a JIT system may not immediately reduce profit, a reduction in service level may lead to customer dissatisfaction, which in turn may lead to brand switching and long-term lost sales and profits. In the face of this type of uncertainty, the need for increased managerial diligence is indicated to control or to take actions to minimize the impact of the uncertainty.

HYPOTHESIS 10

> The presence of both materials management JIT and physical distribution JIT will not produce a positive synergistic effect on service. SUPPORTED FOR ALL SERVICE VARIABLES

The support for this hypothesis was arrived at by a variety of paths. For the order cycle time response variable there were no significant effects at all. For standard deviation of order cycle time there was a significant synergistic interaction of the JIT factors, but it was in the negative direction. For percent customer orders filled, materials management JIT had a significant negative effect. System-wide JIT and physical distribution JIT had significant positive effects, but the two were not significantly different from each other.

The hypothesis was posited on the thought that JIT implementation does not in itself guarantee an increase in service level. The results indicate a tendency toward a negative relationship between JIT and service. Since there have not been similar studies for comparison, these results will have to stand alone pending future research.

For managers the support of this hypothesis suggests that the high service levels associated with system-wide JIT are the results of special efforts and are not a benefit which naturally accrues from adoption of the system.

HYPOTHESIS 11

> The presence of both high materials management operational uncertainty and high demand uncertainty will produce a negative synergistic effect on service. SUPPORTED FOR STANDARD DEVIATION OF ORDER CYCLE TIME

The results for order cycle time as the dependent variable indicated no significant effect from uncertainty of either type. The cell means fell in the rank order to support the hypothesis. If there had been significance in their differences, the values would have indicated the negative synergy posited in the hypothesis. The failure to support can be viewed from three perspectives. First, the relationship does not exist. Second, the test method was too conservative to find the mean cell differences significant or, third, the level of uncertainty in the operationalization was too conservative to produce significant effects. The results suggest that the relationship needs to be explored further in future research.

The results with standard deviation of the order cycle time did support hypothesis 11. The effect of demand uncertainty alone was not significant. While the effect of materials management uncertainty was significant and negative, the effect of both uncertainties together was more negative and significantly different than the effect of just materials management uncertainty. Thus, the hypothesis was supported. The effect of both was more than the sum of their individual effects.

High demand uncertainty had a significant negative effect on percent customer orders filled, but high materials management produced no significant effects. The presence of both uncertainties also produced significant negative results but they were not significantly different from the results of high demand uncertainty alone. Once more, the means fell in the correct order to support the hypothesis, but the conservative methods required when evaluating so many contrasts from a single data set would not allow support of the hypothesis.

For managers the support of this hypothesis suggests the severe negative impact of operational and environmental uncertainty on critical customer service elements. A review of Table 3 indicates that customers find these service elements critical to their efficient operations. For example, three of the studies in the table rated consistency in order cycle time the most important issue in their satisfaction with supplier performance. All managers responsible for the types of material flows represented in this simulation (not just managers with JIT systems), should evaluate the potential for uncertainty in their firm's operations and environment, and consider efforts to control its effects.

CONCLUSIONS

Conclusions from simulation studies may only be relevant to the type of system represented in the model. For this study, an effort was made to represent channel characteristics and JIT system characteristics which are typical of applications in American industry. Japanese success with JIT with different channel and system characteristics should not be held up as evidence of JIT's advantage over alternative systems. The unfavorable JIT results indicated in this study may suggest that much of the current view of JIT as a panacea has been created from the "if it's good there (Japan), it will be good here" mentality often represented in the trade literature. Many American channels differ from Japanese channels which utilize JIT. American channels often operate with less market share, less channel power in the hands of a "channel captain", less flexibility to utilize workers, less government coordination and support, less stability in demand, less willingness to invest in the type of plant and equipment which would be required to truly "produce in lots of one," and more physical distance between echelons which makes consistent material flow difficult.

Except for anecdotal and non-total-system studies, JIT, as it was to be implemented in America, was not investigated before industry began to adopt it. This study suggests how such an investigation could have been conducted to provide insight into JIT channel relationships.

A general conclusion suggested by the results is that JIT is not the unidimensional system often depicted in descriptive and even some empirical studies. JIT effects tend to be complex, interactive and level dependent. Overall generalities concerning how the implementation of JIT is likely to affect a process are not advisable. Without the aid of this type of simulation model running under situation specific conditions or some other analysis technique, it will be difficult for researchers or practitioners to predict JIT's impact on service or profit. It is particularly difficult to predict the effect of JIT on one echelon or subsystems within echelons. A generality about JIT's affect on performance may hold for the channel as a whole, but not for individual operations within it.

One fact that stands out as the results of this study are compared to earlier studies. When the available tools of investigation were relatively weak, JIT responses were observed as simplistic and generalities easily made. As the tools of investigation became more powerful the scientific view of JIT becomes increasingly complex. This is typical of scientific research in general.

Early lack of empirical data allowed JIT to be presented as a simple, material control system with great potential benefits. Further investigations, including the results of this study, suggest that implications of JIT adoption may be far from simple in nature. Instead of a panacea, implementers may indeed face results opposite of those expected.

The breadth of inquiry of this study makes integration of its managerial implications difficult. While the inferences are many, they can be divided into general groups according to the independent variables. The study results suggest inferences about JIT, uncertainty, and JIT with uncertainty, each in terms of both profit and service effect. While they are difficult to consider in isolation from each other, all of these results can have important managerial implications.

There has been evidence presented that consistent material flow is a requirement for efficient JIT operation. Managers should have some means in place of minimizing uncertainty before adopting a JIT system. Similarly critical and even greater negative effects were found when uncertainty was present in the operations and environment of non-JIT systems. This suggests that all managers of operations represented by this simulation should be concerned with the control of uncertainty.

Managers should also consider the form of the JIT system to be adopted. System-wide JIT may not always outperform JIT applied to selected appropriate material flows.

Evidence was also presented that indicated JIT systems may make the job of maintaining high customer service levels and satisfaction more difficult. Extra costs and efforts may be required to develop and maintain processes to meet required service levels.

More research is required into all of these issues. This study's implications for researchers include: the complex nature of JIT (some previous journal articles seemed to portray JIT as a panacea), the importance of full factorial studies (some previous research contended that these types of factors did not interact), the importance of justifying sample size (some previous research used single or arbitrary numbers of observations), and the need for more effort to represent total systems in studies.

This study has indicated how a strategic planner or academic researcher can formally investigate JIT with the newly available and PC based GPM model. With recent advances in computer technology a study of this type can be run and the data analyzed without the necessity of access to often costly mainframe computer time. Advances in computer technology over the past decade allow the PC based GPM model to process more data faster and at less cost than its mainframe based predecessors.

While the results of this study are interesting and provide new insight into JIT, the potentially larger contribution is the successful simulation approach and experimental design. Simulation and factorial models are not original to this study, but the study does provide an easy to follow research procedure. Future research can investigate more focused research questions and utilize less conservative analysis methods. Rather than just accepting that JIT will provide a competitive advantage (because it did in Japan) potential adopters can follow a procedure similar to this study and simulate JIT under their own situation specific conditions.

Contributions to theory (understanding JIT) and practice (predicting the performance of JIT in application) can be derived from the answers (indicated from the research results) to the original statement of research questions from Chapter I.

1. Do all JIT configurations have a positive impact on profit performance?

No. Under a range of uncertainty conditions JIT can have a negative effect on total channel profit. This result disagrees with the "conceptual" research covered in the literature review of Chapter II. Past conceptual research has only emphasized the positive aspects of JIT (mainly inventory reduction). They have avoided consideration of the negative aspects of JIT which were indicated by the results of this study (increased order occurrence cost, increased sensitivity to uncertainty, and the possibility of stock-outs and lost sales). While JIT may provide cost advantages in some areas, efficient operation may require firms to make major improvements in their manner of controlling operational uncertainty, controlling demand uncertainty, transmitting orders, entering orders, receiving shipments, placing products in storage, and processing invoices and billings. Conventional procedures applied to the large number of small quantity orders or releases would likely generate a prohibitively large amount of paperwork. Automated systems to integrate these procedures across echelons may be beyond the financial resources of many firms.

2. Which JIT configuration results in the highest profit performance?

There are some indications that physical distribution JIT may outperform other configurations over a range of conditions. While physical distribution JIT does carry more inventory than system-wide JIT, the disadvantage is offset by fewer lost sales due to stock-outs than both other configurations and lower order occurrence costs than system-wide JIT.

3. How are the results of 1. and 2. above impacted by the presence of uncertainty?

Uncertainty of any kind (particularly demand uncertainty) is often a problem for both JIT and non-JIT material flow systems. This study indicated that uncertainty can negatively impact profit and service levels. This result disagrees with Speh and Wagenheim (1978) (nonJIT), and agrees with Huang, Rees, and Taylor (1983) (JIT) and Forrester (1958) (nonJIT).

4. What are the results of 1., 2., and 3. above when physical distribution service is used as the response variable?

The indications for service variables were similar to those for the profit response, but often displayed stronger effects.

This study's investigation into the details of the relationship between JIT configuration and uncertainty in terms of profitability, order cycle time, standard deviation of order cycle time, and percent of customer orders filled, is a major addition to the information available on the subject of JIT. In the literature review in Chapter II, it was shown that current empirical JIT research has only considered (non-total system) variables such as the following:

1. JIT versus nonJIT in terms of production output.
2. JIT versus nonJIT in terms of overtime.
3. JIT warehouse type 1 versus warehouse type 2 in terms of service.
4. JIT production process uncertainty level 1 versus level 2 in terms of production output.
5. JIT WIP (work in process) level 1 versus WIP level 2 in terms of production output.

This study extends this research by introducing a new simulation model with increased capabilities, utilizing a full factorial design, and testing the response of physical distribution variables. Additional contributions and extensions include:

1. Defining JIT as an integrated system.

Previous definitions in the literature have only represented the limited aspects of JIT relevant to the intended topic and audience. For example, a definition of JIT inventory control only addresses one aspect of a system which can only function efficiently if it is integrated within a larger JIT system of material flows.

2. Establishing the importance of the GST research approach to the study of JIT.

Just as with any logistics system evaluation, the need for a total systems approach may be easy for researchers to agree to, but difficult to fulfill. This study reminds researchers of the implications of the tacit assumptions of non-total-system, non-interacting factor studies, and suggests a total-system alternative.

3. Introducing a research typology to organize JIT research.

Without such an organized representation of past research, it was not generally recognized that total-system / empirical JIT research was lacking, and represented a major gap in the research stream.

4. Developing the elements of physical distribution service across available studies.

While it is known that the importance of physical distribution service elements is situation specific, it is useful for researchers to be aware of those elements which are most often critical across products and industries.

5. Introducing a methodology for the investigation of JIT and physical distribution alternatives in general.

With the availability of the G.P.M. model and the factorial research design, many of the criticisms of total-system investigations as being impractical are rendered untrue.

6. Contributing to the limited empirical literature on JIT.

Prior to this study, little was understood about the effects of different JIT configurations, and JIT material flows under uncertainty. Studies had not investigated the relationship of JIT to total channel profit and service performance.

7. Contributing to the literature on uncertainty in physical distribution.

Since previous studies had investigated the effects of uncertainty on non-JIT systems, it was possible to confirm that the G.P.M. simulation model would produce similar results. An additional contribution was to extend previous findings to include JIT systems.

8. Contributing to the literature on General Systems Theory.

While it has been mentioned that this study may remind logistics researchers of the need for total-system representations, it will also remind General Systems researchers that logistics is a rich area for investigation.

9. Contributing to the literature on Decision Support Systems.

With all of this investigation into the nature of JIT, it is easy to lose sight of the fact that the G.P.M. model itself is a major contribution to the available decision support systems able to represent a multiechelon, multidivision, multiproduct corporation in the various situations necessary for insightful strategic planning. This study presents the model to the decision support system literature stream.

10. Contributing to the literature on Simulation of distribution systems.

While simulation of distribution systems is not new, this study extends the research stream to JIT and presents an ability to investigate interacting factors which had previously been judged too complex to meaningfully interpret.

11. Producing a study which will be the basis for a future program of research.

Insight into this study's implications for future research will be presented in the next section.

RESEARCH LIMITATIONS AND FUTURE RESEARCH

All research is characterized by inherent limitations. It is important for the researcher to advise the reader of such limitations to prevent misunderstanding, misgeneralization, and misuse of the results. It is appropriate to review limitations at the conclusion of a study to help conceptualize a future path for the research stream.

Since potential limitations of this study were detailed in Chapter I, only major issues with potential implications for future research will be mentioned in this section. Examples of this type of issue would include particular restrictions in the model and other factors or factor ranges not explored. An example of the later would be that physical distribution uncertainty was not included because it did not seem compatible with JIT. This is a limitation of the study because this uncertainty is a reality in business systems and should be investigated in future research. A single study often cannot represent every factor the researcher would like to investigate. The solution to the problem is a planned stream of research progressively considering different aspects of the phenomenon.

Even a validated computer simulation of a business system is limited to the extent that it accurately represents the responses of a real world system. A simulation model is configured to represent a particular type of business system and operates with a set of simplifying assumptions. Without simplifying assumptions, simulations are often impractical to construct and the results impractical to interpret. For this study a simple three echelon channel with one product was represented. Stochastic customer demand was non-seasonal and generated from a particular distribution pattern. At each echelon, constraints were not placed on manpower, capital, and capacity to produce.

The relationships chosen to govern the operation of the GPM model and its particular configuration for this study were designed to be as representative of actual relationships in actual business operations as possible. It could be argued that any simplifying assumptions in relationships are a serious problem since systems operate over a wide range of domains. Company operations, policies, environmental uncertainties, JIT systems, and costing systems all vary greatly in the real business world.

The realities of research design counter these arguments. If these relationships had not been constrained and simplified, the result would have been a lack of experimental control, confounding of the effects of factors, and an inability to interpret the results. For these reasons the limitations of this study were not only justified, but unavoidable.

At the end of a research study, it is often beneficial to consider in hindsight, which of the limitations could have been handled more efficiently or in a different manner to yield more information. If the resources had been available, this study may have benefited from a more detailed representation of the echelon cost systems, consideration of the impact of several stochastic variable mean values, and operations within more complex channels. These issues will be the subject for future research designed to further investigate JIT and its impact on channel performance.

FUTURE RESEARCH

The results of this study, often opposite in direction from the research hypothesis (which were based on conventional understanding of JIT), emphasized how little of what is thought to be fact is actually based on empirically tested evidence. Additional research is needed.

Other researchers must independently investigate the relationship of JIT and channel performance utilizing other methods and testing over other domains. For example, experts in operations research may develop a set of differential equations to represent channel operation and test various configurations of JIT by changing functional equations, behavioral researchers using surveys may investigate JIT as a power issue within a channel of distribution, and other researchers using simulation may consider the impact of JIT utilizing other models, other types of channels, and different ranges of stochastic distributions and uncertainties.

This research effort does suggest a wide range of potential areas for future research. One important area for future research would be the introduction of uncertainty in the physical distribution system of the focal organization. It was observed in the present research that materials management uncertainty and demand uncertainty often significantly impacted system performance. Uncertainty in physical distribution would directly affect order cycle time, but the sensitivity is not known, nor is it known how that sensitivity varies under different factor treatments.

Another important area for future research would be to consider the effect of JIT on performance at the echelon level. A JIT system that is favorable to the total profit performance of the channel and favorable to the profit performance of the focal organization may be detrimental to the supplier organization's profitability.

Further research could be conducted wherein the sensitivity of the system response could be explored by expanding the domain of the factor values (i.e., responses over a range of uncertainty and demand values).

Another area of interest would be to vary the price of the product in the channel. This would impact the EOQ value in the non-JIT model and likely change its performance as compared to JIT. Alternatively, two or three products could be introduced to the channel with a range of standard costs, margins, and inventory control policies.

In this same area, future research should investigate the relationships of JIT, profitability, the cost of money, and product value. Are there combinations of interest rates and product values where JIT would not be practical? Over how wide a range of conditions will JIT's affect on service remain constant? Potentially there are many similar relationships concerning JIT performance which should be investigated to either support or disprove conventional thinking. This study has provided one possible experimental procedure and one step in that direction.

ADDITIONAL POTENTIAL HYPOTHESES FOR FUTURE RESEARCH

To test the eleven research hypotheses in this study sixty-seven "F tests" were conducted, with thirty-five indicating significant differences. While the results of the eleven research hypotheses have been discussed in detail, the large number of "F tests" suggest that there is additional insight into relationships that can be derived from the data analysis.

Two additional types of information are available:

> (*) Significant findings that were not "a priori" posited and should not be reported as research findings. For example, if

> a hypothesis required three "F tests" to confirm and only one was significant, the subject of that significant test could be of interest. Another example might be an hypothesis that is not supported but exhibits some other pattern (perhaps the opposite of the expected relationship).
>
> (**) Several hypotheses had the cell means fall in the correct rank order to support the hypothesis, but the value of the difference were not large enough to be significant. These are of interest for future research because the nature of this exploratory study (many tests from one data set) necessitated a conservative multiple comparison procedure. Future research may be designed to investigate one of these particular relationships and may justify use of a more powerful, less conservative procedure.

It should be stressed that this accumulation of relationships is not reported here as research results, but is only presented as an aid to future hypotheses generation and research design.

Each relationship will be identified with the hypothesis from which it came and one or two asterisks indicating which of the two types of additional information, described above, fits the data. In general, (*) suggests a significant finding not "a priori" posited, (**) suggests a non-significant relationship, but the cell means fell in the correct rank order to suggest that a future study using less conservative statistical procedures may find significance. Some will have more than one set of symbols indicating that similar relationships were tested in different places.

1) In the presence of a range of uncertainty conditions, a JIT system has a negative effect on total profit when the entire channel is considered. (H1) (**)

2) System-wide JIT has a negative effect on total channel profit, even under a low uncertainty condition. (H2) (*), (H6) (*)

3) Physical distribution JIT has a positive effect on total profit, across all uncertainty conditions. (H6) (**), (H2) (*)

4) Materials management JIT has a negative effect on total profit across all uncertainty conditions, but a positive effect under only low uncertainty conditions. (H6) (**), (H2) (*)

5) High demand uncertainty has a greater negative profit effect on a non-JIT system than across all systems. (H5) (*)

6) High materials management uncertainty and high demand uncertainty together have a greater negative profit impact on a non-JIT system than for a system-wide JIT system. (H4) (*)

7) High demand uncertainty has a greater negative profit effect than high materials management uncertainty across all JIT and non-JIT systems. (H3) (**), (H7) (*)

8) JIT has a negative effect on the variability of order cycle time, but a positive effect on percent customer orders filled. (H8) (*), (H10) (*)

9) Physical distribution JIT has a positive effect on service variables, while system-wide JIT and materials management JIT have a negative effect. An exception is percent customer orders filled which is positively affected by system-wide JIT. (H10) (*)

10) For system-wide JIT, high materials management uncertainty has a greater negative effect on order cycle time, and variability of order cycle time than high demand uncertainty. (H9) (**), (H11) (**)

11) For system-wide JIT, high demand uncertainty has a greater negative effect on percent customer orders filled than high materials management uncertainty. (H9) (*), (H11) (**)

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