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LINKAGES WITHIN A JUST-IN-TIME ENVIRONMENT
IN THE U.S. AUTOMOBILE INDUSTRY

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A DESCRIPTIVE ANALYSIS OF THE SUBCONTRACTOR/SUPPLIER LINKAGES WITHIN A JUST-IN-TIME ENVIRONMENT IN THE U.S. AUTOMOBILE INDUSTRY

By

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ABSTRACT

A DESCRIPTIVE ANALYSIS OF THE SUBCONTRACTOR/SUPPLIER
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The purpose of this research was to test a generalized Just-In-Time model as it applied to one division of a major U.S. automobile manufacturer. Just-In-Time (JIT) manufacturing has been the subject of great interest in the world since manufacturing managers have become aware of the large potential benefits of JIT as implemented by Toyota and other Japanese manufacturing concerns. Since a great deal of interest about JIT has developed and several companies are implementing JIT, a clear, research-based understanding of JIT is required to produce efficient and effective implementations.

The first step in the research was to develop a general definition and model of theoretical JIT as it could be applied in virtually any environment. This model was then applied to the supply base of the automobile industry, producing a set of theoretical characteristics that could serve as independent variables.

A field study was used, with one division of a major automobile manufacturer and twenty-one of its suppliers providing data for 89 products eventually becoming the data base for statistical analysis.

Analysis was conducted using multiple regression. Only relationships were examined, as the model was intended to be neither causal nor predictive.

Several of the variables were not significant and provided little insight into the model. Other variables, such as receiving information, were not measurable because of data not being available. While not providing data for the analysis, the lack of accurate, accessible records indicates that JIT is still in the early stages of implementation in the division.

Internal supplier characteristics, primarily manufacturing lot size, was related to both customer inventory and supplier inventory. That result implies that, as much of the literature indicates, JIT can only effectively be implemented by establishing close ties with the suppliers and working with them to improve their own operation. Measures of schedule stability, while being significant with respect to total inventory, produced beta values in the opposite direction from that hypothesized. Suppliers apparently do not understand the JIT moves very well, and their possible expediting activity and strategic decisions to maintain unnecessary buffer inventories even with stable schedules have apparently led to the anomoly.

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CHAPTER 1

AN INTRODUCTION

Introduction

This dissertation develops and tests a model concerning the implementation of Just-in-Time processes in a North American automobile company. The model, developed from the early stages of research on Just-in-Time (JIT), presents hypothetically the characteristics of JIT manufacturing as it relates to suppliers. The test, a descriptive field study, examines what relationships these characteristics have with various levels of inventory and determines how important these relationships are. The results may support and direct the development of a paradigm of Just-in-Time (JIT) manufacturing in the North American automobile industry, especially during implementation. This chapter briefly describes JIT manufacturing and the problems in designing JIT research.

Background

Beginning in about 1980, the North American automobile industry underwent numerous shocks from the economy and foreign competition: a dwindling market share, high interest rates, and a deep recession. Among the larger shocks, the industry realized that Japanese manufacturers, their major competitors in the marketplace, could produce their product with very high quality and minimal waste (Schonberger, 1982). Their most dramatic waste and cost reductions were in work-in-process (WIP) inventory. In 1980, for example, Toyota had a remarkably high 62 inventory turns in the manufacturing network (Hall, 1983). Recognizing the cost differences in holding such a small amount of inventory, North American automobile manufacturers sent teams to Japan to study methods, formed study and implementation teams in conjunction with professional societies (e.g., the Just-in-Time subcommittee of the Automobile Industry Action Group [AIAG] and the Zero Inventory Group of APICS), and started to make operational changes patterned after their perceptions of Japanese methods.

To use JIT, a firm must identify the uncertainties in its environment, decide which uncertainties can be eliminated or reduced, and reevaluate the methods it uses to buffer the uncertainties which remain, often finding more effective or less wasteful means of buffering. Thus, JIT reduces the manufacturing waste caused by slack resources, thereby increasing productivity and reducing manufacturing costs.

While this general JIT description appears relatively simple, in practice there are numerous questions regarding the relative importance of implied actions to reduce uncertainties and what alternative buffering strategies can accommodate the remaining uncertainties. Empirical research could help answer some of the questions and clarify theories of JIT, but very little has been done. The subject is, of course, new in the U.S. and there are apparently few examples of advanced JIT implementations to research. There are, however, several companies either beginning to implement JIT or considering doing so.

American literature on JIT has been mostly descriptive. Early works attempted to explain or describe the success of JIT in Japanese companies (e.g., Monden, 1983; Schonberger, 1982; and Shingo, 1981). Virtually no industry-wide statistical research has been done, and only a very few examples exist of other types of research, mostly case studies about such companies as Toyota (Monden, 1983) and Kawasaki (Hall, 1982), and some simulations (Huang et al., 1983; Ritzman et al., 1984).

The earlier works on JIT tended to focus on the characteristics of a JIT system, either as it exists in Japan or as it could exist in almost any manufacturing environment. Once the basic nature of JIT was discovered, however, the focus could shift from specific characteristics to general principles. The supply base (the focus of this study) was, for example, generally listed as but one of several characteristics in the JIT literature. Once examined more thoroughly in the context of general JIT principles, the supply base was viewed as a complex environment in which the JIT principles were applied in basically the same manner as with any other portion of the manufacturing chain. The application of these general JIT principles to the supply base will be developed and explained in detail in chapter three.

The later literature attempted to synthesize the examples of Japanese JIT manufacturing and to derive general characteristics that could be applied in any manufacturing environment or culture (Hall, 1983). This literature describing the basic characteristics of JIT increased theoretical JIT knowledge, but left many unanswered questions about how important and necessary these JIT characteristics were to specific industries.

In attempting to clarify the essential characteristics of JIT, some literature became misdirected--for example, suggesting JIT had only a narrow range of manufacturing applications (Goddard, 1982) or viewing JIT as essentially a lot-sizing technique (Jordan, 1984). In breaking down the principles of JIT and examining them in detail, these investigators lost sight of the general concept of basic uncertainty management inherent with JIT.

Research Design

An opportunity exists for additional research of all types to contribute to the findings of the relatively few case studies and simulations that do exist. Developing a better theoretical understanding of what JIT is and how it works is important, as such an understanding will support efficient, effective, and successful implementations in actual manufacturing environments. A comprehensive model of JIT needs to be built and extensively tested, not only dealing with JIT in the advanced state, but also with JIT implementations.

Wasted or slack resources can include time, space, effort, capacity, and inventory. Wasted inventory can include buffer stocks, obsolete or rejected material, and cycle stocks (material produced most efficiently in quantities exceeding demand). The strategies for reducing and accommodating uncertainty can also take many forms, affecting, for example, both manufacturing operations and relations with suppliers. The research in this study focuses on one form of waste (buffer inventory) in one major portion of the total manufacturing process (the supply base) in one environment (the automobile industry).

North American industry, especially the automobile industry, has made progress in implementing JIT (Hall, 1983; Manoochehri, 1984).

Within the automobile industry, changes in the supply base appeared first and were perhaps the most significant (Lorincz, 1985), even though the supplier network appears not to be the portion of the system where an implementation should begin (Hall, 1983). Several supply base programs were underway in the automobile industry during design and data collection for this research, including programs such as statistical process control (SPC) to improve quality, systems to promote rapid exchange of information (including computer linkages), and programs to reduce the supply base and create closer relationships with "survivors."

As I discussed this research project with industry managers and decided on its design, it became apparent that these managers had, in many cases, either an incomplete or an incorrect concept of JIT. They tended to believe it was either an inventory reduction or an inventory control tool and that it produced little if any effect on the operation of the company outside the materials function.

Many supplier managers also fostered misconceptions, tending to see JIT as an attempt to force them to hold inventory previously held by the automobile companies. They could see little advantage to or effect on their companies, except a possible increase in business if their firms were among the "survivors" when the automobile companies reduced the size of its supply base. Those suppliers who did understand JIT fairly well were, for the most part, reluctant to implement it aggressively. They tended to be very cautious regarding the motives of the automobile industry and were afraid that the automobile companies would abandon JIT without making any meaningful changes. JIT might be just another one in a series of faddish programs quickly abandoned by the automobile industry.

In spite of the confusion about JIT in the automobile industry and its supply base, the literature review and subsequent management discussions both led to the conclusion that the most extensive attempt to implement JIT in North America was in the automobile industry. Furthermore, the earliest comprehensive efforts were in the supply base. Therefore, the supply base was the logical arena in which to conduct descriptive empirical JIT research. The large automobile producers have clout with their suppliers, and it seemed easier to create change there than within the automobile manufacturing plant itself, according to several automobile industry and supplier managers.

There were difficulties in conducting JIT research in the automobile industry, beyond the obvious ones of the industry's size and diversity and the relatively early stages of JIT implementation. As indicated earlier, much misunderstanding concerning JIT existed. Many appeared to view JIT as a new technology for inventory control, rather than as a "philosophy" of manufacturing (Melnyk et al., 1984) and most did not perceive the potential organizational and strategic changes implied (Chapman, 1984). In addition, implementation of Just-in-Time (JIT) systems had not progressed very far in the automobile industry. Relatively comprehensive JIT implementations had been either Japanese owned (e.g., Nissan, USA), or designed very recently with JIT in mind, or both. Internal implementations (not including the supply base) in existing North American owned operations appeared to be, with a few exceptions, mostly small pilot projects. Therefore, this research is general and descriptive in nature, and not predictive or causal. It seemed most appropriate to assemble empirical data which might indicate the effect of hypothesized JIT characteristics on inventory and the relationships between all measured variables. The data gathered would have little subjectivity, yet would imply which relationships discussed in the JIT literature and developed in the model were most important.

Chapter two summarizes the literature and draws conclusions from this review. Chapter three describes a model based on the literature review and on industry discussions and presents hypotheses generated from the model. Chapter four presents the method of data collection and analysis techniques. Chapter five presents the result of the analysis. Finally, chapter six presents conclusions and suggests further directions for JIT research.

CHAPTER 2

A REVIEW OF JIT LITERATURE

Introduction

Hall (1983, page 10) states that JIT (or, using his term, stockless production) "is not confined to a set of techniques for improving production defined in the narrowest way as material conversion. It is a way to visualize the physical operations of the company from raw material to customer delivery, but there is no aspect of management which it does not touch." Given the integrative nature of JIT, the literature review examines how JIT affects the entire business, not just the supply base.

Just-in-Time gained much interest because it could apparently allow a manufacturing facility to produce high quality products to meet market demand with smaller levels of waste and higher levels of productivity (Hall, 1983). JIT reduces waste while maintaining (and possibly even improving) customer service because it identifies and changes conditions of manufacturing which cause waste to exist. The changes include reducing manufacturing uncertainties as well as accommodating remaining uncertainties with more cost effective techniques.

The literature focuses on several characteristics of JIT, most of them apparently being interrelated to some degree. For instance, if manufacturing eliminates inventory in process without having value added, production is made virtually to market demand, often daily in small lots. Virtually every item produced must be of good quality, since no buffer exists. In addition, with no buffer to absorb machine downtime, there must be a preventive maintenance program which minimizes potential downtime. The small, frequently issues inventory replenishment lots extend back to the suppliers, as does the demand for quality. In short, as much of the literature implies, JIT represents a comprehensive change in the basic planning and control structure of manufacturing.

Before 1981, only a few articles in the West (e.g., Cutterbuck, 1978; Sugimori et al., 1977) even mentioned the concepts of JIT. But in the early 1980's a long and deep recession, coupled with increased manufacturing costs and foreign competition, made JIT and its apparent benefits of great interest for manufacturing concerns in specific and business in general. As Harper (1985, page 49), put it, "The concept borrowed from Japan is one of the hottest and most controversial subjects facing distributors today." This interest in JIT is apparent among distributors, suppliers, and manufacturers, especially if their products face foreign or domestic competition from producers using the principles of JIT effectively. Articles and books on the subject have grown correspondingly, as is evident in the size of the accompanying list of references, virtually all of which have been published during or after 1981.

This chapter summarizes the JIT literature relevant to this research. General JIT literature that develops JIT characteristics is examined first, followed by JIT research, and finally the literature specifically discussing JIT in the supply base.

General JIT Literature

During the 1970's and the early 1980's, business conditions were apparently building toward a major shift in the manufacturing environment for many Western firms. Researchers and managers began to recognize that many of the previously acceptable methods of planning and control were not performing well in the changing environments. As Schonberger (1982, page 4) describes it:

> "Consumptive, profligate habits probably grew in America and Canada roughly in parallel with the growth of a middle class. The trend was interrupted during the World War II years when the countries needed--and got--reliable war supplies and equipment. Following the war, the growth of middle-class consumerism was rapid. The trend would surely have continued unabated had not the OPEC-induced oil shock of 1973, as well as the raw material shortages beginning about 1971, occurred."

The oil shocks, Schonberger continued, led to world-wide shortages of primary materials and much higher costs for those materials that were obtainable. Responses to the problem differed. "While Japanese industry was perfecting just-in-time materials management and factory control, the West searched for political and economic solutions to the energy/material cost dilemma. OPEC had to be pressured, the oil companies had to be watched, consumers had to conserve energy, and government had to tinker with taxes, tariffs, and quotas" (Schonberger, 1982, page 5).

Market conditions were changing at that time, as well, particularly in the automobile industry in North America. The Japanese products gained market share (Schonberger, 1982) as the North American public perceived that the Japanese products were often lower in cost and higher in quality. As interest developed in learning how the

Japanese did what they apparently did so well, teams of American business people were organized and sent to Japan to investigate. They found results such as these:

TABLE 2-1

COMPARISON OF HOOD AND FENDER PRESS PLANTS, 1978

	Toyota	American Plant
Setup Time (Hours)	0.2	6.0
Setups Per Day	3.0	1.0
Lot Size	1 Day Use	10 Days Use
Strokes Per Hour	500-550	300

Source: Hall, 1983, page 25.

TABLE 2-2

AUTOMOTIVE ASSEMBLY PLANT LABOR DAYS

	Toyota Tokaoka Plant	Plant A United States
Number of Employees	4300	3800
Number of Vehicles Per Day	2700	1000
Total Labor Days Per Vehicle	1.6	3.8

Source: Hall, 1983, page 25.

TABLE 2-3

MANUFACTURING INVENTORIES

Company	Days On Hand	Annual Turnover
Toyota Motor Company (1980)	4.0	62
Tachikawa Spring Company (1982)	3.3	75
Jidosha Kiki (1982)	3.2	78
Kawasaki Motorcycle, Japan (1981)	3.2	78
Kawasaki USA (active parts) (1982)	5.0 est.	50 est.
Tokai Rika (1982)	3.7	68
American Competitors (1981)	10-41 est.	6-25 est.

Source: Hall, 1983, page 25.

The literature warned, however, that there were some fundamental differences between Japanese and Western manufacturing which might make JIT nontransferable, and that further study and research was needed. For example, Hall (1981, page 7, indicates that "there is no single, easily stated reason for this phenomenon--no magic formula. It is necessary to go through the entire background of it, studying and restudying, until the Western mind grasps how the Japanese have combined many different practices into a very successful overall system." Hall indicates the very different cultural environment in Japan, and continues the discussion by isolating four characteristics which contribute to Japan's industrial growth: limited space, few natural resources, a common culture and race, and a group oriented culture.

The Characteristics Generators

As the literature on JIT proliferated in response to the growing interest, authors attempted to describe the characteristics of JIT as they posted reasons for its success.

Wantuck (1983) describes the characteristics as "tactics" (page 663), classified under two major headings "Respect for People" and "Elimination of Waste." Under these two major categories Wantuck list fourteen points, similar to those in several other pieces of literature. The Automobile Industry Action Group (AIAG) adapted Wantuck a list of JIT characteristics. The AIAG is attempting, through its JIT subcommittee, to provide direction for a unified approach to implementing JIT throughout the automobile industry in North America, including the supply base (Callahan, 1984). Table 2-4 summarizes JIT characteristics as described by three of the major authors in JIT: Wantuck, Hall, and Schonberger.

It should be evident from Table 2-4 that three authors agree that several characteristics are important, but each omits or refers only indirectly to characteristics mentioned by one or both of the others. This is evidence that JIT is understood differently by the authors examined. For example, Wantuck lists focused factories but Hall does not: Hall lists design engineering but Wantuck does not. Hall's list is more action-oriented: the group technology on Wantuck's list, for example, could accomplish the actions on Hall's list of streamlining flows and linking material flows to final assembly. Further comparisons with other authors' "lists" can bring further complications. Lee and Ebrahimpour (1984), for example, bring in governmental support as a requirement, while Baxter (1982) makes a

TABLE 2-4

A COMPARISON OF JIT CHARACTERISTICS
FROM JIT LITERATURE

JIT Characteristics	Hall	Wantuck	Schonberger
Kanban System	S	S	S
Stable Schedules	S	S	S
Focused Factories	N	S	S
Group Technology	S	S	S
Preventive Maintenance	S	N	S
Machine Automation	S	S	R
Quality Control	S	S	S
Product Design	S	N	N
Rapid Inventory Transportation	S	S	S
Setup Time Reduction	S	S	S
Unions	R	S	R
Participative Management	S	S	S
Quality Circles	S	S	S
Supplier Networks	S	S	S
Market Pacing	S	N	R
Strategic Implications	S	N	R
Shop Floor Communications	S	N	R
Line Balancing	S	R	R
Education Programs	S	N	R
Process Design	S	N	R

N = No direct reference.

R = Referred to indirectly or without detail.

S = Specific treatment.

controlled transportation system and geographic concentration primary elements. These examples demonstrate different approaches to generalizing the concepts, a condition which continues as much of the JIT literature is examined. In general, JIT literature included different characteristics, not all the characteristics were presented in the same context, and not all the characteristics were represented with the same level of importance. Several works fit the pattern of generating JIT characteristics, including the works of Andrew (1984), Cook (1984), Hall (1981 and 1982), Harmon (1982), Levin (1984), Manoochehri (1984), McGuire (1982), Nakane and Hall (1981 and 1983), Pendlebury (1984), Schonberger (1982, 83, and 84), Stone (1982), and Youngkin (1984). These others mentioned are essentially variations of the same characteristic generating concept, each providing their own "list." A manufacturing manager or researcher attempting to conceptualize JIT using only these works could interpret their messages as conflicting. Implementations could take very different directions, depending on which set of characteristics was accepted and what level of importance was assigned to each.

Some of the characteristic generators did attempt to progress beyond mere description of the author's concept of JIT. These works attempted to suggest specific implementation procedures for JIT. Hall's Zero Inventories (1983) expands on the implementation list in his 1982 piece, and provides a great deal of detail, explanation, and several good examples, making it probably the best and most complete work in the JIT implementation literature.

Aside from Hall (1983) and Schonberger (1982), few authors attempted a deeper level of understanding than that provided by lists of implementation characteristics with varying degrees of explanation and detail. Most authors view JIT as a technology, a set of rules or techniques to apply for a specific outcome, rather than as a framework of thinking or even a philosophy (Melnyk et al., 1985). But a few do take a more theoretic approach. Melnyk and Carter (1982) describe Kanban as a unique form of a classical (s,Q) inventory ordering system. Wieters (1982) views inventory as a buffer against uncertainties and the JIT system, because its goal is to reduce the uncertainties, as reducing the need for the buffer and increasing the need for interdependence.

Additional JIT attempt to expand beyond characteristic generation, including Landvater (1984) and Baxter (1982). Both of these works point out that existing systems (MRP, in particular), if operated properly, can provide successes comparable with JIT and may be more compatible with current U.S. manufacturing environments. These authors doubt whether JIT can apply in U.S. plants, because of basic cultural and environmental differences between Japanese and U.S. businesses. Landvater, for example, implies that the real problem for U.S. manufacturers today lies with scheduling problems, not with characteristics identified with JIT. Similar arguments are found in Goddard (1982), Jordan (1984), and Wight (1981). Jordan pursues the argument, (page 142) that "the key to reducing leadtimes and inventories is found in the correct application of lot sizing techniques."

Other authors have a different opinion on whether JIT is compatible with other systems, most often citing MRP or MRP II. As examples, Nellemann (1982), Sandras (1984), Sonnenburg (1983), Everdell (1984), and Edwards and Anderson (1984) all produce the same general message. They show how the MRP bill of material explosion and planning logic can be incorporated in a comprehensive JIT implementation, providing basic scheduling and capacity planning information to the operation.

The essential difference in these points of view is how each interprets the nature of JIT. Those who see JIT as incompatible with other systems tend to view JIT in a narrow focus, almost as an alternative to existing systems. Those who believe JIT is compatible with other systems see it in its more global framework, recognizing its adaptability and generalizability. This viewpoint promotes a much larger range of application environments and final system configurations; in fact, almost any logical support system could provide a benefit to JIT implementation.

Research

There are few advanced JIT implementations in North America. Therefore, very little JIT research has been published, and what has been published fits into two categories--case studies and simulations. In spite of the proliferation of conceptual descriptive literature described earlier, both researchers and managers need more concrete data on JIT. The case studies and simulations have provided data and detail that encourage empirical field research, but none has been published.

In some cases, even before literature appeared describing JIT in detail, manufacturers and researchers were aware of the apparent cost advantage of many Japanese companies and the high quality of their products. The manufacturers and researchers were intensely interested in the manufacturing methods employed to accomplish the documented results. This interest culminated in the publication of Japanese companies case studies--books and articles describing not so much what basic manufacturing principles the Japanese employed but how the

Japanese employ them: Hall (1981), Hays (1981), Monden (1981) and (1983), Myer (1980, Shingo (1981), and Wheelwright (1981). All these works describe with varying degrees of detail the elements of JIT as applied by the Japanese (primarily Toyota). The most detailed are the works of Shingo (1981) and Monden (1983). Shingo was an industrial engineer with Toyota during the development of JIT, and was instrumental in developing and implementing the concepts. Such a perspective provides both a unique and detailed view of JIT in Toyota.

These works primarily described specific elements of JIT application in the Japanese environment. Those elements included the Kanban card system, quality circles and participative management principles. The complete list is extensive, but the main elements were presented earlier in more generic terms (Table 2-4).

This literature described a very specific application in a business environment different from North America's. Most of the works were case studies describing Toyota production and made the startling comparisons presented earlier in Tables 2-1, 2-2, and 2-3. These Japanese manufacturing cases created perhaps as many questions and problems as they solved. They did not determine how generalizable the applications were, in what environments JIT could work, or how much modification JIT needed to work in other environments. Even the terminology was subject to confusion, as the early works appeared to use Kanban and JIT interchangeably, although Kanban was the card-based information system that was but one of the JIT techniques. Other terms for JIT (Zero Inventories, Stockless Production) surfaced and are still used, but it appears "JIT" has emerged as the most common term.

The first case studies of Western manufacturing were written about JIT implementations in companies owned and/or managed by the Japanese. Hall's case study (1982) of Kawasaki, U.S.A., for example, focuses on applying Japanese JIT in a more western environment. He makes special note of the Japanese JIT principles which either did not work or required modification to work, but did not attempt to generalize the modifications. In concluding, Hall notes that, even after reducing inventory by forty percent and increasing productivity by twenty percent "for the Lincoln Plant to match Akashi in total performance would take five more years" (page 8). Since implementing JIT is an extensive undertaking and may never be completely finished, it will be several years before we will have a case study on North America industry where implementation is more than in its earliest stages.

The Hall case describes well the environment and decisions required to implement JIT in the Lincoln Kawaski plant, but it did not generalize or summarize the concept of JIT further than Shingo (1981) had in describing the more complete JIT implementation in Toyota. This and other case studies of Western JIT implementations demonstrated that the concepts could be transferred to a different cultural and business environment and that the implementation require organizational changes, some of them extensive. The changes, including quality control, scheduling, preventive maintenance, participative management, and others listed earlier in Table 2-4, could also be expected to take a great deal of time and effort to implement.

Another example of the extensive time required to develop JIT and associated case studies was Copeman's "Conversion From MRP to

JIT - A Case Study" (1984). This case described moving from MRP to JIT scheduling at Double A Products by using group technology, focused factory management, and finally a pull system using containers as the replenishment signal. The author himself acknowledged that, seven years after implementing group technology, the company still had much to do to fully implement JIT, including expanding the pull system to other product lines and bringing the supply base into a JIT mode of operation.

Additional case studies indicated that JIT could succeed in Western manufacturing sites and illustrated different ways of implementing it. They included studies of JIT implementations in companies such as AP Parts (Cicak and Hay, 1983), Harley-Davidson (Gelb, 1983), General Motors (Glen, 1984), Kawasaki, U.S.A. (Hall, 1982), Damrow (Hatch, 1984), Hewlett-Packard (Hunt, Garrett, and Merz, 1985), Motor Wheel (Melnyk, Chapman and Uzzle, 1984), and Northern Telecom, Ltd. (Powell and Weddell, 1984). They all indicated that JIT had been implemented with different degrees of success in companies with differing products, environments, workforces, and other resources. They did not, however, contribute to a generalized model of JIT because of the diverse nature of the operations and environments, though they might provide support for a generalized model when one is developed.

The cases did provide at least two additional contributions. They showed that an implementation could be approached very differently in different environments, and they encouraged continued interest and research in the area. Their diversity further indicated the need for extensive and detailed research on JIT.

Simulations represented the most rigorous and analytic of the research accomplished to date, best represented by Huang et al. (1983) and Ritzman et al. (1984). Both provided interesting and insightful looks at possible JIT manufacturing situations. Unfortunately, because of the extensive, interrelated characteristics of JIT already described and the lack of a specific paradigm upon which the simulation could be built, any simulation had to incorporate numerous variations.

Ritzman et al. find results consistent with much of the descriptive literature. They found, for example, that slack in labor capacity was the most valuable buffer, particularly when large lot sizes created bottlenecks that shifted unpredictably from one place to another. They also found that the manufacturing environment rather than Kanban counted in JIT success. Kanban was but one convenient way to implement small-lot production with a minimum amount of paperwork while revealing problems in the production process.

The Huang et al. simulation was not quite as supportive of the JIT concepts, finding that JIT is generally not applicable to a typical North American production environment characterized by variable processing times, variable production schedules, production bottlenecks, and fluctuating demand patterns. Since JIT attempts to reduce the variation in these environmental characteristics, it could be argued that Huang et al. did not really simulate JIT at all, but only reduced work-in-process inventory. Monden (1984) responded to the pessimistic viewpoint of the Huang et al. article with the opinion (page 445): "Contrary to what the authors assume, a variable processing time in the American worker, if it exists, is not an environmental factor within American production systems; rather, it is a decision variable resulting from the standardization of jobs that is inherent in the original technology of industrial engineering in America."

Literature Dealing with the Supply Base

As JIT understanding grew, the literature tended to describe in more detail the specific elements or phases of JIT implementation. The research of interest to this study is that dealing with the supply linkages, but very little research or literature existed in the supply base in a JIT environment, aside from a few conceptual articles and a chapter or section of the more complete works on JIT, Hall (1983) and Schonberger (1982).

In general, purchased materials account for a larger portion of the cost of goods sold in the Japanese than in the North American automobile industry. As an example, Schonberger (1982, page 174) points out that Toyota's expenditures for purchased materials accounted for nearly eighty percent of its sales dollar, while the figure was less than fifty percent for General Motors. Toyota did, however, maintain an ownership interest in a number of its suppliers.

Much of the difference could be explained by the size and purpose of the suppliers in question. If one accepts Hall's supplier classification (1983), suppliers can be categorized into two classes: Type I, suppliers capable of producing the material at a lower cost than the customer can, and Type II, suppliers possessing skills the customer does not have and cannot easily develop. Hall (1983, page 203) points out that "because of its industrial history, Japanese suppliers frequently started more as type I suppliers than as type II. Many more

American suppliers started as type II. Japanese OEMs frequently started supplier companies themselves in order to obtain lower costs."

Japanese original equipment manufacturers (OEMs) typically have a history of long-term relations with suppliers that may never be duplicated in the U.S. Hall (1983), indicates that a contract with an American supplier could go sour for many reasons, and that the purchasing manager should constantly monitor the performance of suppliers with alternatives in mind. The purchaser, Hall continues, does not have the tradition of long-term relationships to fall back on. In fact, according to Hall (1983, page 206), "a purchasing agent pursuing the kind of working arrangements used by Japanese companies could run afoul of a number of laws." He was not specific as to what laws might have been involved, and the literature has no other references to potential legal problems with JIT supply if a company tried to imitate the Japanese JIT experience, but the possibility creates a concern that should warrant future research.

Because of Japan's geography and because of the long-term relationships of suppliers to automobile manufacturers, Japanese suppliers tended to locate much closer to their customer than the U.S. counterparts did. Japan is small in comparison to the U.S., and many of the industries are located in close geographical pockets. Bartholomew (1984) indicates at least one potential effect of this difference. The auto firms and their suppliers agreed nearly unanimously that JIT could not operate on a stand-alone basis. Most felt that a time-phased system would also be required, predominately for logistical reasons. U.S. automotive suppliers, he maintained, were frequently not as geographically convenient as their counterparts in Japan, making daily deliveries unavailable. The issue here is not whether a supplier can make daily deliveries, but what the cost would be. Daily deliveries imply small quantity deliveries, and the cost of a small quantity delivered over a long distance would probably be impractical from a cost perspective.

A given customer in Japan tended to use fewer suppliers than one in the U.S., often because of a single-sourcing policy. Manoochehri (1984, page 18), made one comparison:

> "Most American manufacturers use a larger number of suppliers than do their Japanese counterparts. In auto industry, for example, most manufacturers use two to three vendors for each purchased part. As a striking contrast, General Motors uses a total of more than 3500 suppliers, while Toyota uses fewer than 250. The large number of suppliers utilized by GM created a number of problems.
>
> 1. It is more difficult to manage the coordination of production schedules and relationships.
>
> 2. More suppliers require that more time and money be spent in developing and training them.
>
> 3. When several suppliers are utilized for the same part, it becomes less practical for each supplier to make frequent deliveries of the same part."

Bartholomew (1984) recognized an additional advantage of single-sourcing in the Japanese system. He compared the number of Nissan Motor's suppliers (460) to Ford's (2500) and found the basic difference between them was Nissan's greater willingness to use single sources. Ninety-eight percent of Nissan's horns were produced by one vendor, allowing that vendor to engage in long-term research and development and to acquire capital equipment. The supplier realized productivity gains, and the customer realized cost savings. In general, single-sourcing was almost universally recognized in the supply JIT literature as a significant characteristic of Japanese JIT.

Western companies also have different relationships with their suppliers than do Japanese JIT customers and their supplier companies, according to the literature. As Manoochehri (1984, page 19) summarizes the situation: "In contrast with the overall Japanese experience, American buyers and their suppliers are not as genuinely concerned with mutual benefit and profitability. At times, the relationships even become somewhat adversarial. American buyers tend to focus much more heavily on cost. This general attitude has produced extensive use of the competitive bidding process among American firms." Much of the literature indicated a bond of mutual trust between Japanese JIT companies and their suppliers, while their U.S. counterparts held negotiations at arms-length. These close relationships and overall trust have practical importance in JIT, since manufacturers need rapid, accurate, and complete sharing of detailed information with the supply base (Manoochehri, 1984).

Engineering design and quality systems for purchasing are also distinctive in Japanese JIT companies, especially with the general increased emphasis on quality. Schonberger and Gilbert (1983, page 61 states that "Just-in-Time purchasing is facilitated by 'loose' design engineering specifications, 'on the fly' value analysis, and close cooperation between engineering, quality, and purchasing managers." Close, cooperative relationships in the engineering and quality areas is another characteristic apparently facilitated by development of trust between the JIT company and its suppliers.

The substantial differences between Japanese JIT suppliers and the typical Western supply imply that JIT will develop differently in a Western environment than it has in Japan. According to Hall (1983, page 230), "no one supposes that Americans are going to emulate Japanese cultural practice in supplier relationships. However, the need to form competitive industrial supply networks will force some revision of the current methods of doing business." According to Manoochehri (1984), it may be impractical for American firms to attempt to emulate the Japanese JIT experience, but modified versions of the basic concept could be beneficial in many major U.S. firms. As a model is built for Western implementation of a JIT supply base, the Japanese experiences can serve as a foundation, but the substantial differences summarized above, indicate modifications will be required to reflect a different supply linkage environment.

Schonberger and Gilbert (1983, page 58), describe the characteristics of a generalized JIT supply base, reproduced here as Table 2-5. Many of the characteristics derive from the Japanese model, and this list is representative of others in the literature.

From the literature examined and summarized above, the application of JIT concepts in the Western manufacturing supply base appears to represent some significant changes in the way that a typical Western firm approaches business dealings with suppliers. Two additional questions implied by the differences are approached in the literature.

1. Can JIT work in the West?
2. How is JIT purchasing working here and how are the modifications that appear so essential taking shape?

TABLE 2-5

CHARACTERISTICS OF JIT PURCHASING

Suppliers

- Few Suppliers
- Nearby Suppliers
- Repeat business with same suppliers
- Active use of analysis to enable desirable suppliers to become/ stay price competitive
- Clusters of remote suppliers
- Competitive bidding mostly limited to new part numbers
- Buyer plant resists vertical integration and subsequent wipeout of supplier business.
- Suppliers are encouraged to extend JIT buying to their suppliers

Quantities

- Steady output rate (a desirable prerequisite)
- Frequent deliveries in small lot quantities
- Long-term contract agreements
- Minimal release paperwork
- Delivery quantities variable from release but fixed for whole contract term
- Little or no permissible overage or underage of receipts
- Suppliers encouraged to package in exact quantities
- Suppliers encouraged to reduce their production lot sizes (or store unreleased material)

Quality

- Minimal product specifications imposed on supplier
- Help suppliers to meet quality requirements
- Close relationships between buyers' and suppliers' quality assurance people
- Suppliers encouraged to use process control charts instead of lot sampling inspection

Shipping

- Scheduling of inbound freight
- Gain control of use of company-owned or contract shipping, contract warehousing, and trailers for freight consolidation/storage where possible--instead of using common carriers

Source: Schonberger and Gilbert, 1983, page 58.

The answer to the first question appears to be "yes." Schonberger and Gilbert (1983) state that people who are steeped in U.S. purchasing practices react to JIT with, if not disbelief, then complete confidence that it won't work here. However, Schonberger and Gilbert (1983, page 56) declare that they "have found that JIT purchasing will, and is, working in the U.S."

The second question is and will continue to be much more difficult to answer. The consensus of several articles is that the automobile industry represents the most visible, if not the most progressive, implementation of JIT purchasing. According to Lorincz (1985, page 74), "Maybe it is enough to say that the JIT concept is complex and that it is not being practiced in the U.S. in its purest form. The one possible exception often cited is what is being done in the automobile industry."

The National Screw Machine Products Association (NSMPA) recently conducted a survey within their membership to determine what suppliers were finding as buyers moved more toward JIT. The results, reported in an article by Lorincz (1985), indicated that suppliers were confused and that the industry lacked direction in moving toward JIT. Suppliers also seemed to expect both a significant change in the way of doing business and a possible steady-state condition of JIT that may be unique in the world, and certainly different from JIT in Japan. As an example, Lorincz (1985, page 74), provided a summary of some of the NSMPA survey results:

" - There is no uniform, consistent approach to JIT. Suppliers face a variety of programs or no programs at all.

- If the use of long-term contracts is a measure of an OEM's dedication to JIT, then most customers of its industry are not strongly supporting JIT.

- There is little infrastructure and incentive to support JIT. Most suppliers will not take JIT seriously until OEMs do.

- Complying with JIT initially increases cost for the industry and forces suppliers into very difficult long-range, high-impact decisions."

Lorincz explained the basic decisions, mentioned in the last point of his summary, faced by the supplier. Suppliers must decide between accepting long manufacturing runs and maintaining inventory to accommodate more frequent release dates, or implementing some form of JIT manufacturing in their own operations in order to match releases with those of their customers. In general the article and the results of the survey indicated a fair degree of confusion and uncertainty in implementing JIT purchasing.

One additional point in the literature was critical in understanding the current state of JIT purchasing, especially in the automobile industry. As Hall (1983) indicates, the proper procedure for implementing JIT purchasing is to stablize the internal environment first and then expand to the supply base, as was done in Japan. In the numerous informal conversations with automobile industry suppliers during the design and data gathering phase of this research, I observed that most suppliers, either from ignorance of the choices or from a conscious decision based on uncertainty, had decided to maintain inventories (when possible) as a buffer. Because their customers frequently changed release data, many suppliers saw JIT methods as little more than the use of clout. The large and powerful automobile companies could force necessary inventories back on the supply base, and the long-range contracts which were part of JIT made it more difficult for the suppliers to quickly recover the additional costs by passing on price increases. This position has been supported to some extent by automobile industry managers, indicating that implementation of JIT purchasing in the automobile industry may have progressed in a direction exactly opposite that recommended by Hall. The effect of such implementation is unknown, but it should be considered when evaluating the success of the implementation and the outcome of research investigating the progress of the implementation.

In general, the characteristics of JIT supply analyzed in the literature led to an overall conclusion that the supply base in a Western implementation of JIT is likely to be quite different from that existing in Japan. That statement was supported as indicated in the articles described above. Examining the supply base in Japanese JIT is, therefore, not appropriate for developing an understanding of Western JIT. A separate paradigm needs to be developed and researched.

In the early literature, there was an understandable lack of empirical research. The literature was characterized by sometimes confusing, contradictory statements of what JIT is and how it should be implemented. The more recent literature takes a more fruitful direction, developing generalized, detailed models were for possible future implementation and research. JIT is a new area of study for researchers and manufacturing managers alike, but the interest has been sustained long enough to warrant increased attention toward building theories, constructing a paradigm of JIT, and testing and supporting the paradigm with comprehensive research efforts.

CHAPTER 3

DEVELOPMENT OF THE RESEARCH MODEL

JIT literature leads to the conclusion that significant changes in the supply base of all Western industries attempting JIT implementation should be expected. The literature review further demonstrates some inconsistencies and a general sparsity of JIT research, leading to a general conclusion that a meaningful JIT model needs further development and testing. This chapter will develop the general JIT concepts in more detail and, in conjunction with JIT supply characteristics developed in the literature, build a model of JIT supply for testing with the field study data. The term "model" in this discussion is used in the sense of establishing a group of expected relationships being neither predictive nor causal.

The Research Problem

As indicated by both the literature and discussions with industry management, a great deal of interest developed recently by manufacturing managers anxious to achieve some of the potential Japanese JIT benefits. It also became apparent that no clear, consistent, agreed-upon model of JIT existed. Potential misconceptions and inefficient or ineffective implementations of JIT principles were a possible result. A clear, generalized model of JIT needed to be built and tested.

This research is intended to be but an early step in the overall process of generalized JIT model building and testing. Since virtually no empirically tested model exists, descriptive research such as this could potentially provide an important base from which to build further research and development of a generalized model. Specifically, this research is a descriptive field study designed to examine the relationships and relative importance of various hypothesized JIT characteristics to inventory in the supply base for a representative of the U.S. automobile industry as the automobile industry representative is involved with JIT implementation. The automobile industry supply base was chosen partly for the reasons detailed in Chapter 2 (i.e., early implementation), and partly for convenience and availability.

Important Definitions

Before proceeding to the details of a JIT model, JIT should be defined or described in more detail. Most of the literature fails to mention a specific definition at all, a situation understandable given the integrative and almost philosophical nature of JIT (Melnyk et al., 1984). As a result, the definition is really more of a description of JIT, and represents a conglomeration of understanding developed from the literature, primarily Schonberger (1982) and Hall (1983).

Just-in-Time manufacturing produces to market demand with minimal total waste in the system. JIT manufacturing is accomplished by:

a. direct elimination of waste

b. reduction in the uncertainties in the manufacturing environment that can promote waste

c. accommodating uncertainties by methods leading to higher overall productivity.

For a JIT application, waste is defined as any aspect of the production system which causes lower productivity (output/input). Hall (1983) identifies four types:

a. time

b. energy (e.g., equipment running)

c. material

d. errors (e.g., rework/scrap)

Development of the Model

The need to develop a research model forces a reexamination of some of the JIT literature presented earlier. JIT superficially appeared to focus on the elimination (or the constant reduction and control) of waste in the manufacturing system. The waste could be in any form, including scrap, rework, poor productivity of people, and capacity. The form of waste that had gained the most interest, however, was inventory waiting to either be placed in transit or having value added in the manufacturing process. Inventory in queue had a high visibility and, for most companies, a relatively high cost.

Waste reduction is really both a goal of JIT as well as a useful way to measure the success of the implementation (Hall, 1983), but the real "heart" of a JIT implementation is changing manufacturing conditions so that the waste reduction can occur without creating problems in the basic purpose of producing to market demand with minimal total cost.

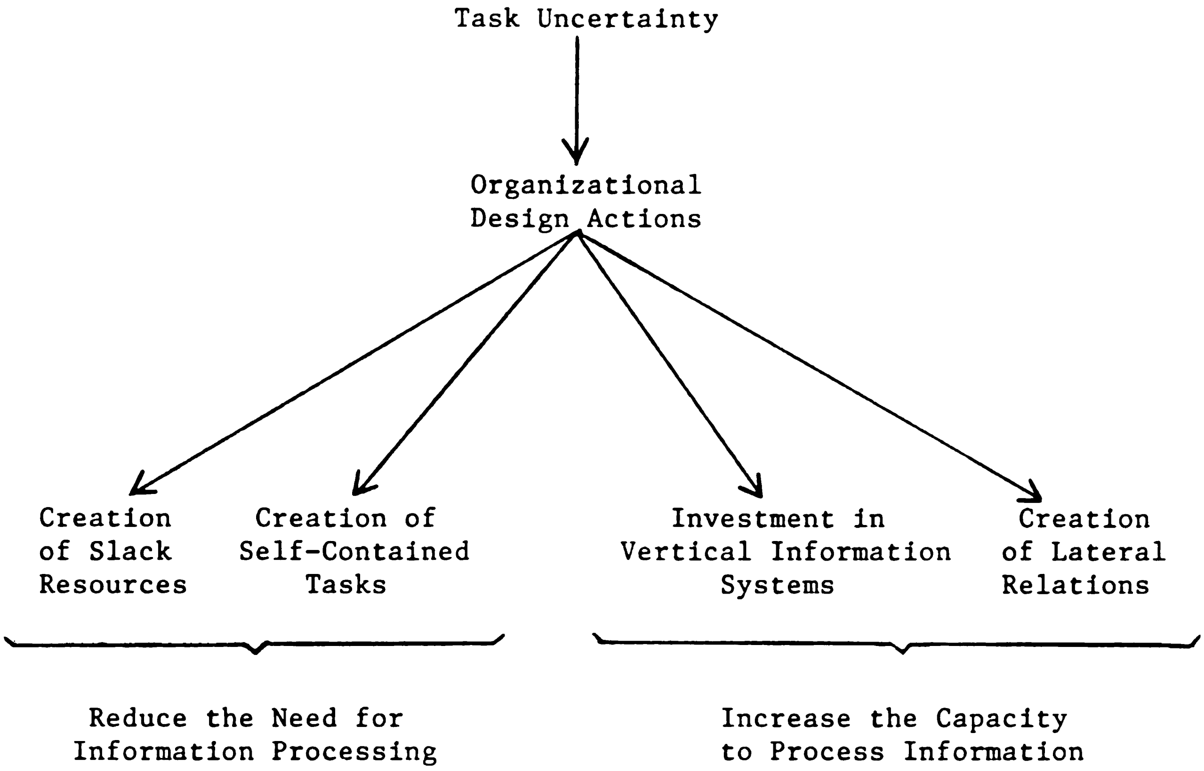
In this framework of JIT, the changes in the manufacturing conditions occur in basically two ways:

1. Reducing uncertainties in such areas as information accuracy, information timing, product quality, etc. in the manufacturing system. Prior to JIT implementation, such uncertainties were generally buffered by slack resources, identified in a JIT system as waste. Uncertainties almost always exist in the operation of any organization, but the organizations have been able to accommodate the uncertainties by holding excessive (buffer) resources such as material and capacity. As an example, if a machining center was to produce one hundred parts but typically had a ten percent scrap rate, the production requirement might have been increased to one hundred and ten (or more) pieces to accommodate the uncertain quality. The extra ten pieces, whether of acceptable quality or not, represented a waste. Reducing the uncertainties allows for reduction of the buffers with little increased risk in disruption of customer service.

2. Changing the methods to deal with the uncertainties to forms that may be more cost effective for the given environment. These can be categorized by the organization uncertainty model developed by Galbraith (1974), as detailed below.

A close examination of the Galbraith model and its relationship with JIT is appropriate to make the specific research model clearer. The basic concept of the Galbraith model is that any organization is faced with the need to deal with some level of uncertainties in the environment and that these task uncertainties faced by the organization are solved primarily by organization design changes. These changes have two basic categories, each with two specific tactic options (in each case an example is included to clarify the nature of the action involved). A graphic representation is given in Figure 3-1 as adapted from the Galbraith model.

Change 1: <u>Reduce the need to process information</u> concerning the uncertainties. Essentially this change means the organization has established some method to buffer or isolate various portions of the organization from the potential disruption of uncertain environmental



Source: Galbraith, 1974

ADAPTATION OF THE GALBRAITH INFORMATION PROCESSING MODEL

FIGURE 3-1

influences, making it easier for the organization to accommodate the uncertainties when they occur or allowing fewer uncertainties to reach isolated portions. The specific tactics are:

> Creation of slack resources. This very common manufacturing organization action can include many types, but the most obvious are extra (buffer) inventories, excess manufacturing capacity, and buffer (queue) time built into the planning lead times of the product. When, for example, the requirement for a given product from a customer exceeds the expected demand for that product within the product lead time of the product (an uncertainty), the organization can still accommodate the extra demand by using either buffer stocks of inventory, lead time compression of the queue time, or both.

<u>Creation of self-contained tasks</u>. Probably the best example of this action is the development of the focused factory concept (Skinner, 1978). In this concept, a manufacturing environment is broken into discrete and isolated conceptual "factories," with the idea that the "factory" can focus its attention on one set of internally consistent goals. The manager responsible for that area or "factory" has only to process information concerning their own specific area, allowing them to better accommodate and handle the uncertainties that do affect their area.

Change 2: <u>Increase the capacity to process information</u>. This change method also accommodates the uncertainties that affect the organization, but instead changes the ability of the organization to respond to the changes by tying together information processing activities within the organization. Such linkages increase the flow of information concerning both uncertainties and actions to accommodate them. The specific actions include:

<u>Invest in vertical information systems</u>. Such a system links upstream and downstream production operations to allow for efficient and accurate information flow. A vertical information system may be a comprehensive computer system that includes all activities of the organization from customer orders to the supplier information in the same data base, or it could be as simple as the Kanban card system employed by Toyota (Monden, 1983). The key concept here is that upstream and downstream information are tied together in the same information system in order to better accommodate uncertainties and the information surrounding them.

<u>Create lateral relationships</u>. Galbraith (1974, page 33) states that lateral relationships "employ selectively joint decision processes which cut across lines of authority. This strategy moves the level of decision making down in the organization to where the information exists but does so without reorganizing around self-contained groups." This action accommodates uncertainty information processing in that it puts the proper people or systems across the organization together, allowing decisions to be made more effectively with more complete information. Examples of this activity include such concepts as matrix structures, task forces, and quality circles (group meetings and

decision making activities involving all concerned individuals at all levels responsible for a defined area).

In the context of the JIT model being developed here, the organization is trying to cost effectively cope with the environmental uncertainties by either reducing the uncertainties (thereby reducing the need to accommodate the uncertainties) or by more effectively accommodating the uncertainties that exist by using changes in organizational design. This JIT model is not inconsistent with those developed in the literature (such as Schonberger and Hall) but is, in fact, supportive of their models. Models such as those developed by Schonberger and Hall, however, tend to focus on characteristics of JIT, such as quality control, quality circles, schedule stability, and others described in the previous chapter. The question that is invoked by those descriptions is why the characteristics are important. The model presented here attempts to deal with that "why" question. When a JIT model based on Galbraith is presented, it becomes clear that any activity within the organization that either reduces uncertainty or accommodates it in a more cost effective manner becomes consistent with JIT and is important in the implementation of JIT. The characteristics of JIT presented in much of the literature can simply be condensed into basic reasons presented in the general JIT model. They can either directly reduce waste, reduce uncertainties, accommodate the uncertainty in a more cost effective manner, or some combination.

One of the best publicized JIT goals (and the one that brought initial attention to many North American manufacturers) is the reduction of inventory as a form of waste. While inventory has many functions in a manufacturing environment, one of its primary functions is to buffer (as a slack resource) the organization against uncertainties in the environment. These environmental uncertainties include:

- Schedule fluctuations due to

  > Market conditions

  > Material availability

  > Options

  > Engineering changes

  > Mistakes (e.g., incorrect production reporting, transcription errors, data entry)

  > Inaccurate data bases (e.g., Stock Status, Bills of Materials)

- Product quality

- Machine availability

- Upstream or downstream production rates

- Downtime for setup changes

As suggested in the JIT literature, JIT implementation should concentrate on significant reduction of inventory and other forms of "waste" in the manufacturing environment. This waste can be reduced by three activities in the organizational model presented, assuming the organization does not desire as a strategy to be more vunerable to environmental shocks (Meyer, 1982):

1. reduce the uncertainty that forces the buffer of the slack resource (waste in the JIT context)

2. provide for a different tactic, as in the Galbraith model, to accommodate the uncertainty more efficiently

3. provide for an alternative (more efficient) form of slack resource as the buffer.

An analysis of the JIT characteristics as developed in the literature and discussed in the previous chapter can show that virtually every characteristic fits one or more of the three alternatives above. Several examples are provided for illustrative purposes, primarily using the fourteen points developed by Wantuck (1983) and adopted by the AIAG:

> Focused Factory Networks (as described earlier) essentially represent a different way of handling uncertainties, or the creation of self-contained tasks (better able to accommodate uncertainties) in the Galbraith model.
>
> Group Technology (GT) represents several concepts at once. Group Technology involves reorganizing the manufacturing layout into cells, with each cell producing a "family" of products. The families are selected based on similarities of processes and setups. The very act of setting up a group technology cell implies a reduction of setup times (as the "family" members to be manufactured in the cell are selected at least partially on the basis of similar setups), a reduction in the need for material handling as all the processing equipment is located in the same cell, a simplification of scheduling as the cells are independently scheduled, a simplification of the requirement of keeping track of inventory as it is virtually all located in the same cell, and the general reduction of manufacturing lead times as all the other characteristics take effect. In the context of the earlier analysis, these GT activities accomplish the following:
>
> 1. Reduction of waste, as less inventory is needed (shorter setup times imply the ability to use smaller lot sizes), less time and waste in material handling, and less scrap as less radical setups imply faster and fewer machinery adjustments.
>
> 2. A different way of handling uncertainties, as the manufacturing cell is designed to accomplish virtually all the processing activities for a given product and may be considered a self-contained task. In addition, since GT usually is accomplished with some duplication of machinery not

typically found in functional layouts, the extra machinery represents excess capacity existing above the usual requirement. The excess capacity is another form of slack resource.

3. A reduction of uncertainties, as the cell layout places all inventory and processes for a given product in the same physical area. Such close physical proximity makes it easier to track, schedule, and maintain accurate inventories of the jobs in the manufacturing environment.

Quality Control represents both a reduction of waste (scrap) as well as a reduction of an uncertainty (whether a given piece of inventory is usable).

Stable schedules characterized by virtually no variation in quantity or production mix for a set time period, represent a major reduction in uncertainty. While all uncertainty cannot usually be eliminated from a schedule, reduction of the uncertainty allows for reduced accommodation activities within the organization.

The Kanban card system described in Monden (1983) and Hall (1981 and 1983) represents a new way of handling uncertainties, in that it could be viewed as a simple but rapidly acting vertical information system providing information on both product requirements and inventory movement authorization for a given work center and linking that work center to both upstream and downstream activities. The two major cards in the system are the production card and the move card. The production card, allowed to be unattached as the associated produced inventory is used by the downstream operation, provides information on production requirements. The move card, required to move raw material from the upstream operation, helps transmit (in conjunction with the upstream production card) information as to raw material requirements for the operation in question.

Lifetime employment (job security) can be viewed as a reduction of uncertainty, for both the employee and the company. Managers are more certain of both the number of employees and the skill levels of those employees. The knowledge of which and how many employees are available helps define the manpower capacity available, and the skill level of that capacity.

The points above provide examples of how the literature-based JIT characteristics can be explained in the context of the Galbraith model. Once JIT is understood in the Galbraith model context, a very rapid narrowing of JIT concepts can be made in order to specify the model to be used in this research.

Because of the early attention to JIT characteristics in the automobile industry supply base (as described in the last chapter) and the accessibility of a willing subject, the field study selected to test the JIT model concentrates on one portion of the automobile industry supply base. While it is recognized that the supplier/subcontractor network is but one of Wantuck's (and AIAG's) fourteen points, the findings could provide substantial support for the theoretical JIT model based on Galbraith's organizational design model. In addition, as indicated earlier, supply base JIT is not theoretically different in its approach to JIT, only in the specific tactics employed to implement it.

Using the Galbraith organizational design model in conjunction with JIT characteristics developed in the literature, the customer-supplier relationship should be expected to have the following characteristics in a JIT environment. The model assumes JIT existing in the network itself (affecting both supplier and buyer), and not merely in one side of the relationship or the other. The characteristics will be briefly described together with the reason they exist in terms of the general JIT concepts presented earlier. There is no specific significance in the order of presentation:

1. Delivery lot sizes and inventory levels will be small (waste reduction), facilitated by a stable release schedule from the buyer (uncertainty

reduction), short delivery times (waste reduction), rapid, accurate information flow (accommodating remaining uncertainties), and reliable delivery of product (uncertainty reduction).

2. Supplier Manufacturing lot sizes and lead time will be small to match delivery lot sizes (waste reduction), facilitated by internal supplier activities to reduce or accommodate uncertainties (setup reduction, preventive maintenance, quality programs, information systems, flexibility of capacity, etc.).

3. Quality of transferred material will be very high (uncertainty and waste reduction), facilitated by internal supplier quality programs.

4. Receiving inspection activities will be eliminated or significantly reduced (waste reduction), facilitated by product quality and the establishment of supplier reliability records (uncertainty reduction).

The basic supplier model suggests that the supplier-buyer linkages will be characterized by the same basic uncertainty reduction, waste reduction, and uncertainty accommodation goals as the internal manufacturing environment. Only the characteristics that develop as these goals are manifested may differ in some aspects.

The Specific Research Model

The specific research model consists of multiple independent variables, a single dependent variable (measured in three stages), and other variables measured for statistical control. An attempt was made to measure independent variables that reflect the key items mentioned in the literature and the supplier-buyer JIT model developed earlier. Within the context of the theoretical understanding of JIT, the independent and dependent variables fit into three basic categories:

- pure "waste," in the context of JIT developed in the first chapter

- uncertainty variables, although most represent some reduction of waste as well

- timing elements, contributing to both waste and uncertainty (variability and uncertainty are increased by an extention in the time required to perform manufacturing and supply functions).

Descriptions of the independent variables follow. Unless otherwise indicated, the relationship to the dependent variables is hypothesized to be positive and all variables measured as averages are averaged over the past calendar year from the date of data gathering. In addition, the model presented here assumes no interaction among the independent variables. The variables and hypothesized relationships are described here:

Waste

1. Average lot size delivered to the purchasing company, measured as a percentage of annual customer demand (number of pieces in average lot divided by annual demand) in order to control for the level of usage of a particular item. A lot size of 10,000 pieces, for example, may represent less than a week's supply of some items while it may represent a full year's usage of another. As lot sizes are delivered representing larger percentages of annual demand, the average inventory held will be larger, assuming a relatively constant rate of usage. Inventory waiting without having value added is considered waste in the context of JIT. This variable was hypothesized to be significantly related to both customer inventory and intransit inventory, with those significant relationships producing a relationship with total inventory.

2. Average supplier manufacturing lot size, as reflected in the supplier planning system. This was also standardized as a percentage of annual demand. This variable represented an attempt to capture several internal variables inherent in the supplier manufacturing system. The lot size presumably reflected the use of basic lot sizing algorithms taking into account demand, setup cost, inventory holding cost, etc. As with delivered lot size, larger manufacturing lot sizes (as a percentage of annual demand) imply a larger average inventory, viewed as waste in JIT terms. The expectation with this variable was a strong relationship with supplier finished goods inventory, assuming the

customer had control over delivered lot size. Under that assumption, the variable should not have had a significant relationship with customer inventory. The relationship with supplier inventory should have produced a corresponding relationship with total inventory.

Uncertainty

3. Product quality, operationally defined and measured as the percent of shipments accepted at the receiving inspection facility of the purchasing company during the previous year. This measurement did not account for the disposition of rejected material, only that the material was rejected. While, as was indicated earlier, poor product quality represents an element of waste, the primary importance in this model was the uncertainty it brought into the system. The expectation was that lower product quality would have been related to higher inventory levels at both the supplier and customer facility (and therefore a hypothesized negative relationship), as both facilities would theoretically have extra inventory as a buffer against the uncertain quality.

4. Quantity changes demanded by the purchasing company during the past year within the quoted lead time of the product, as reflected in the releases from the purchasing company. This was measured and operationally defined by using two variables. The first was the number of times that changes occurred during the past year, while the second was the average magnitude of the change (again standardized as percentage of annual demand). Both measurements were collected by requesting the suppliers involved to review the release histories from the customer and provide summary data. The expectation was that both frequent changes and larger quantity changes would have represented a significant uncertainty for the supplier, thereby hypothesized as being related to supplier inventory (and subsequently total inventory) as the supplier attempted to buffer against the uncertain demand.

5. The on-time delivery record of the supplier product over the past year, measured and operationally defined as two variables. The first was the percentage of total deliveries either late or early (late and early deliveries divided by total deliveries), while the second was the average

magnitude of the earliness or lateness of the delivery in days. What constitutes early or late was left to the discretion of the receiving facility, as it is there that the uncertainty will manifest itself theoretically in buffer inventories. An additional reason to leave the decision to the facility was that some type of sensitivity screen should be necessary. Some material would represent a problem if it were one hour late, while others might have been days late without being noticed. Theoretically, in a "pure" JIT facility, there would be no difference, but in this study the most effective method of controlling for significant delivery time variations was to measure those that were noticeable to the facility receiving the material. Delivery time variations should theoretically be significantly related to customer inventory, as the customer facility provides buffers against the uncertainty of demand. In this specific supply base, however, a great deal of sensitivity to on-time delivery was expected, based on the informal discussions held during the research design. As such, a restriction of range was expected to yield little significance in the model.

Timing

Longer times for each of the following variables means that inventory decisions will need to be made further into the future, where the demand for the product is faced with larger uncertainties. Such demand uncertainties should theoretically be associated with excessive inventories established as a buffer against the larger uncertainty.

6. Average supplier delivery time during the past year, operationally defined and measured as the average number of days that the inventory took to move from release to the transportation system by the supplier until it was received by the customer receiving system. This variable is intended to capture the primary elements of the delivery system, including supplier distance and transportation method (although the transportation method will also be measured separately). The specific distance is not as important to the customer as is the combined potential effect of distance and transportation method--speed of delivery and delivered

lot size. This variable was hypothesized to be highly related to intransit inventory, as longer transit time is usually reflected by more inventory in transit. In addition, as the uncertainty of product demand increases with increased time, a relationship should have been noticed with customer inventory (a buffer against the uncertainty).

7. Average supplier manufacturing lead time in days, as reflected in the supplier planning system. This variable was the other major variable (the first being supplier manufacturing lot size) intended to represent not only uncertainty due to timing, but also intended to capture additional information about supplier internal manufacturing data, including complexity of the manufacturing process (setup times, control complexities, machine downtime, etc.). The hypothesis was that this variable would be significantly related to total inventory, but most significantly with supplier finished goods as the supplier recognized the need to buffer against the uncertainty associated with timing.

8. Information lead time, measured as the average time in days it takes for information to be reflected in the supplier information system after it has been released by the purchaser. The information from the customer was dated, giving the supplier the ability to determine the average elapsed time for the information to be included in their data systems. The hypothesis was that this variable would be related to total inventory, but strongest with supplier finished goods as they were expected to be aware of the lead time and buffer against a perceived delay in getting the information to the data base.

9. Average capacity change lead time, measured and operationally defined as the average time in days it takes the supplier to change capacity in response to the average weekly release quantity change from the purchaser. In addition to being a timing variable, a shorter capacity lead time together with excess capacity available (also to be measured), are interpreted in the Galbraith model as key accommodating factors that could buffer the organization in place of buffer inventory. This variable alone, however, was primarily a timing variable and therefore hypothesized to be most significantly related to supplier finished goods inventory as the supplier presumably buffered against the increased demand uncertainty associated with timing.

10. The receiving throughput time, measured as the average time in days it took a product to move through the receiving process from delivery on the dock until it is released for production in the purchasing facility information system. A longer receiving throughput time theoretically would prompt the purchasing facility to maintain a buffer of raw material for use while the receiving activity occurs, bringing a hypothesis that this variable would show the strongest relationship with purchaser of raw material inventory.

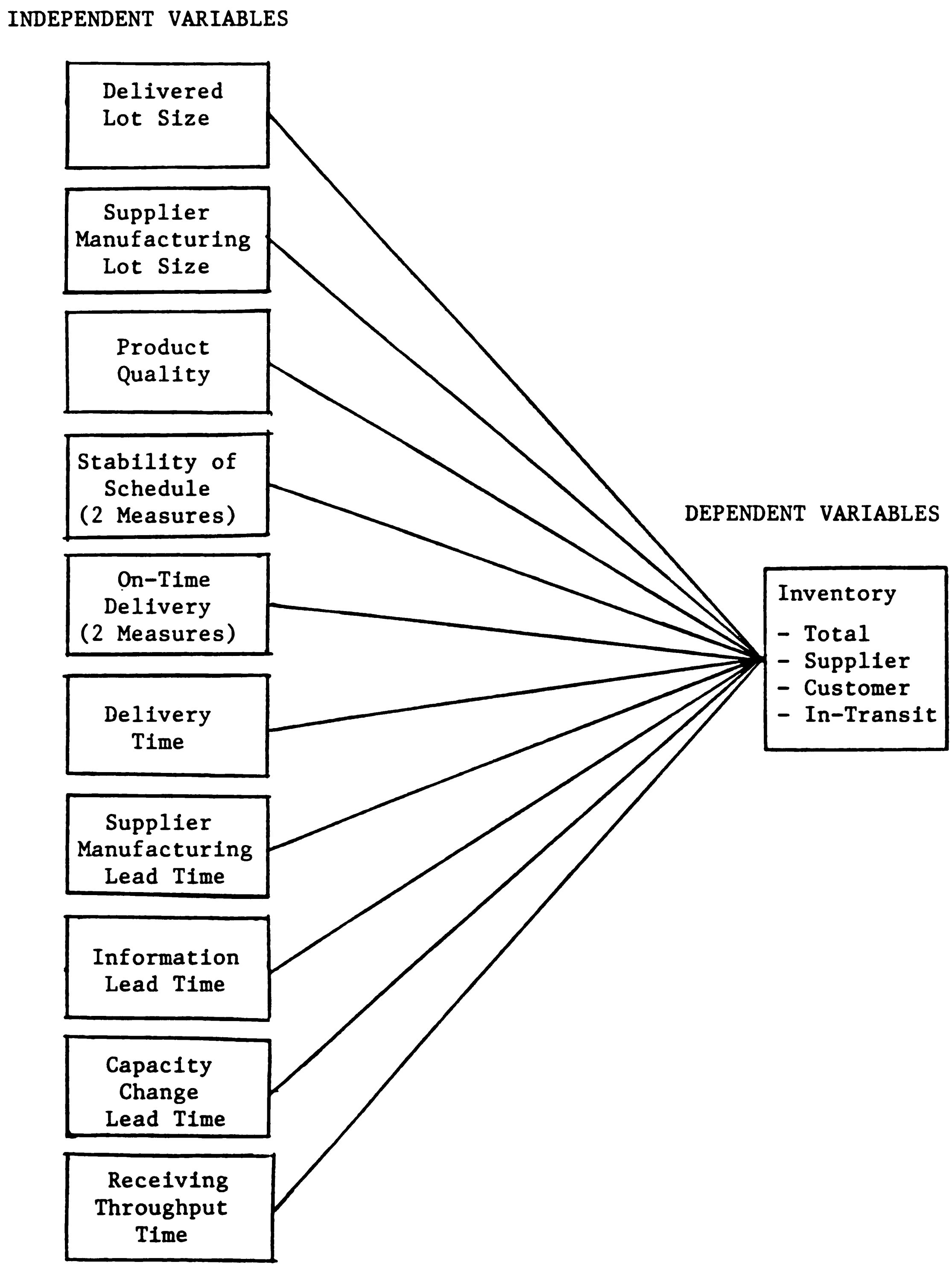
The relationships described above are summarized here in Figure 3-2.

Dependent Variables

The prime dependent variable measured was total inventory in the supply network of the product. This measurement required three separate measurements--supplier finished goods prior to shipment, in-transit inventory in the transportation system (regardless of who "owned" the inventory), and product received at the purchasing facility but not yet released for production. All of these were also standardized as a percentage of annual demand by dividing the actual number of units by the annual demand of the product. While recognition is given that inventory is but one form of waste that a JIT system should focus on, inventory is one of the largest and most visible forms, and should be used as a primary measurement of how well a facility is accomplishing a JIT implementation (Hall, 1983).

Methodology and Subject Selection

A field study was selected to attempt to test the model of the supply base in a JIT environment. McGrath (1979) suggests such a study is most appropriate when a researcher is attempting to build a



INDEPENDENT AND DEPENDENT VARIABLES

FIGURE 3-2

paradigm, as it attempts to provide a little knowledge about a very wide area.

In an attempt to minimize the unmeasured variability in the model and to provide for better statistical control, the suppliers selected and the parts in the study were all involved with one division of a major automobile producer (MAP). Assuming that the customer (the division of MAP) provided basically similar treatment of and information to all suppliers, the primary variation in the measurements would come from the suppliers and distribution systems involved. Multiple customers could have produced untraceable variability, limiting the ability to make strong statements about possible relationships. In addition, the suppliers involved were requested to select products at random from among those which were supplied only to the specific division of MAP. In that way, all inventory was meant for only the one customer and confusion was reduced when supplier finished goods inventory quantities were measured. The unit of analysis was the specific product produced for MAP by the supplier in the study, with the data gathered from information concerned with each specific product.

Statistical Control Variables

Additional variables were measured to obtain some statistical control in reduced regression analysis. These variables were intended to reflect both the ability of the supplier to respond to the changes of schedule and systems as well as the importance of the specific product to the supplier and to the purchaser. Relationships between independent and dependent variables in the reduced model were calculated while holding as constant the effect of the following:

1. Supplier size, in dollars of annual sales. Smaller suppliers could possibly be more flexible to respond to the changes and could also be more sensitive to the pressures placed on them to change.

2. The number of products produced by the supplier for all customers. This variable is intended to provide an indication of the complexity of the supplier manufacturing system. More complex systems are not as likely to see significant changes made rapidly, as both the amount of work necessary to change a complex system and the capital investment necessary to make the changes increase.

3. The number of suppliers for the product. The literature suggests that JIT will promote, through its theoretical requirement of close coupling of organizations, a move toward single sourcing. This variable, in conjunction with the two variables immediately following, could provide not only data reflecting the possible moves toward single sourcing, but could provide insight into a relationship between the importance of the business to the supplier and the amount of apparent JIT changes the supplier has made with respect to their customer.

4. The percentage of annual demand of the product supplied by the supplier. The concerns here were essentially the same as those with the previous variable.

5. Annual supplier sales to the purchaser in dollars. Suppliers with large sales to MAP could have experienced more internal and external pressures to conform to the JIT moves of MAP.

6. The percentage of excess capacity of the supplier. As indicated earlier, this variable represents a source of a slack resource that could substitute for inventory, especially if the lead time to bring this capacity on line is relatively short.

7. The primary method of transportation for the product. This variable, representing the only nominal variable in the model, could have been used to provide insight into delivery lot size impact, especially when viewed with transportation timing. The assumption was that some relationships would exist between lot size and transportation method, as certain methods (train, for example) will carry larger lot sizes than other (airplanes, for example).

Assumptions and Limitations

The model was, by design, a descriptive model. As such, it is expected to provide only indications of relationships from which more specific and detailed research could build refinement of theoretical models and perhaps identify causality. Many of the variables in this model had a potential of having several "hidden" characteristics which could produce confounding effects. As an example, most individual supplier manufacturing characteristics were measured merely by the measurement of supplier lot size and manufacturing lead time. It was not known what, if any, effect some of these hidden characteristics could have produced in the model, although the literature did not suggest any large impact.

In addition, since several of the measurements were made as averages over the past year, some other assumptions needed to be made. No specific measurements in this area were made, as they would have been highly subjective and preliminary discussions with both supplier and MAP management indicated that no major violations of the assumptions existed. The assumptions included:

1. Stability in the economy, eliminating the quest for liquidity through inventory reduction inherent with recessionary times.

2. No significant technological changes in the product or process used to produce the product. Technological changes could bring about changes in lot sizes, lead times, quality levels, and general uncertainty concerning the stability of the process to produce the proper volume of the product. The uncertainty surrounding the changes could have also resulted in safety stocks of inventory in excess of that amount normally carried.

3. No independent programs of inventory reduction at either the supplier or the purchaser.

4. No strikes or impending labor problems for either the supplier or purchaser. The potential for labor problems leads many firms to buffer themselves with extra inventory in the event of labor slowdowns or walkouts.

5. No significant capacity modifications, especially at the supplier. Capacity modifications could affect inventory levels, as capacity may be a substitute buffer against uncertainty for many products.

6. Consistency of top management policies for both suppliers and purchaser. Top management policy changes could affect acceptable or desired inventory levels, labor skills and availability, relationships with customers and/or suppliers, and virtually any other aspect of the company assumed to be generally fixed during the data gathering period.

7. Consistent variability of the measurements, meaning that those variables measured as averages are not significantly affected by a few outlying measurements.

8. A reasonably effective planning system, especially on the part of the supplier. This is important since the planning system will affect many of the supplier variables, such as lot sizes, manufacturing lead times, and information lead times.

9. Reasonably accurate information systems, meaning that the data supplied by all parties in the research was an accurate reflection of the actual situation.

The basic research model is intended to be analyzed by multiple regression, but has the potential for extensive analysis in parts. The specific selection of subjects and description of the analysis will be presented in the next chapter.

CHAPTER 4

METHODOLOGY

Now that the general JIT model and specific research model were developed, data gathering and analysis activity could proceed. This chapter describes the details of site and subject selection, the data gathering activity and measurements, and the analysis procedures for the research.

Site

As indicated in the last chapter, the unit of analysis for this study was to be specific products supplied to the one division of MAP as non-commodity (supplied only to the one division of MAP). The MAP division (MAPD) had a large number of parts supplied (over 9500) by more than 820 suppliers representing a variety of size and complexity. This study was intended to describe the JIT activity in just the one convenience sample (and not, therefore, generalizable), but a good description still dictated a degree of variability in the sample. This variability is supported by the following statistics describing the twenty-one suppliers contributing data:

	Mean	Range
Size (dollars sales)	$45 Mil	$750 Mil to $8 Mil
Total Number Products	69,000	1,000,000+ to 50

MAPD produces a wide variety of products, ranging from "high-tech" computer-based modules to fairly basic and stable products that have had little design modifications for many years. They also manufacture products with fairly simple designs but subject to wide varieties of design changes and options, such as tail lenses (taillight assemblies) and wiring harnesses. The products they purchase from suppliers reflect the variety in the products produced by MAPD.

MAPD had been implementing several JIT activities for, in some cases, more than two years. Quality circles had been implemented in every plant, and each of the plant quality circle projects had an active coordinator. Statistical Process Control (SPC) had been promoted for more than two years, and was especially active within supplier plants. MAPD had even designated a special department at the division level to coordinate the SPC activity with suppliers. JIT projects in the early implementation phase included transportation coordination, computer information linkages with suppliers, group technology, and enhanced product design coordination with engineers. Other JIT projects primarily in the planning phases included standard containerization, stablization of schedules, and Kanban control systems.

MAPD recognized that its JIT activities were being hampered by a lack of complete JIT understanding at virtually all levels of the organization. They attempted to solve the problem by appointing a divisional coordinator for JIT implementation and establishing a series of internal seminars to teach JIT principles. In addition, many of the MAPD plants had their own plant JIT coordinators. These coordinators had developed both internal education programs and JIT implementation projects to varying degrees of completion.

Sample Selection and Variable Measurements

In this study, the suppliers selected represented three major groups--electronic suppliers (resistors, computer chips, etc.), molded plastic suppliers, and suppliers of machined products. Of the 89 products used as the basis of this study, 57 came from the plastics group, 24 from the electronics group, and 8 from the machining group. This distribution was not surprising given the restriction that the products be non-commodity. Plastic products and machined parts tended to fit the unque-design category much more readily than did electronic components, plastics tended to represent more part numbers in the item master file than did machined parts.

The data was collected from the sample during the period of May 1985 through September 1985. The following section details the methodology for selecting the sample and collecting the data, problems encountered, and resolution of the problems.

In the period of March 1985 to April 1985, discussions were held with the personnel responsible for the purchasing systems at MAPD staff in order to determine the most effective and convenient method to approach suppliers and gather data. The decision was made that a sample of suppliers from this one division of MAPD would accomplish two goals of the study. First, since the buying is done at a divisional level, the purchasing activity from the customer to the supplier would be fairly homogeneous across suppliers and purchased products. This was important, as any variability in the act of making a purchase was not to be directly measured and should be controlled for as much as possible. Secondly, it was important for statistical analysis and potential establishment of significant results that the range of measured variables be maximized within practical limits, reducing the potential for range restriction problems. MAPD purchases products with a wide range of characteristics (including electronic devices and plastics) from suppliers with large cross-sections of size, complexity, and other purchasing variables in the JIT model. As such, the MAPD supply base appeared to be well suited for a descriptive study such as this.

One of the practical restrictions on the size of the sample came from the available resources and time within MAPD. While each supplier selected from the sample would be asked to provide data concerning but a few part numbers, MAPD personnel would need to provide internal data for the entire sample. In order to maximize the sample size, maintain as much randomness as possible, and yet minimize the impact on any one individual within MAPD, it was decided to conduct a meeting with all buyers who would be willing to participate in the data gathering. The purpose of the meeting was to explain the study and to request support and assistance with data gathering. At that meeting (held in late April 1985), each of the eight buyers in attendance (representing about one-third of the total) was asked to select a random group of suppliers they worked with to ask for supplier participation. Each buyer was asked to ultimately provide a list of five participating suppliers. Ten buyers eventually provided supplier names, as two buyers not at the original meeting later agreed to help with the study. Some overlap of supplier names did occur, as the buyers are organized along product lines. It is possible that one major supplier could be working with several MAPD buyers, depending on the product involved.

Randomness of supplier selection was stressed to the buyers, but because suppliers had to agree to participate and contribute a fair amount of potentially sensitive information, a certain amount of self-selection was probable and expected in the sample. The amount of possible bias from self-selection was unknown, but discussions with buyers indicated a minimal effect.

The request for randomness of part number selection was equally stressed to the suppliers, but it is again expected that some self-selection did occur as some suppliers indicated that their poor data bases prevented data gathering for some of the products initially selected. Other problems they mentioned that prevented pure randomness were design changes in progress, inactivity of selected part number, and, in one case, a supplier only supplying two products in total to MAPD. Nevertheless, most suppliers indicated that they used a random selection as much as possible, with the data gathering problems estimated to represent less than a ten percent rejection level.

In the course of the next six weeks, the buyers provided names and contact individuals for 31 suppliers. Each supplier was then contacted personally by telephone to explain the purpose of the study and a description of the requested data. Each was asked to select, at random, five part numbers that they produced exclusively for MAPD. They were each then sent a form to provide data for each part number. A sample of the form can be found in Appendix A. Each supplier was given assurance that the data would be confidential in that specific data representing a specific supplier would not be shared with either other suppliers or with MAPD personnel. The twenty-one suppliers that returned the forms represent sixty-eight percent of those contacted.

Since the design of the study was cross-sectional, time became critical at this stage of data gathering. Too much elapsed time could change unmeasured conditions assumed to be fixed, thereby confounding the result. Nevertheless, many suppliers were slow to respond, and often required two or three followup telephone calls. Even with the followup calls not all responded, and some suppliers provided data for less than five numbers (correspondingly, some suppliers provided data for more than five numbers). By the end of August, twenty-one suppliers had provided data for 95 part numbers. That number represented 2.6 percent of the total suppliers, 1 percent of the active MAPD part numbers, and 71 percent of the total products possible if all contacted suppliers had contributed as requested.

Once data were received from a supplier, internal data from MAPD could be gathered. The only link to MAPD internal product data was by the MAPD part number supplied by the supplier. Some of the numbers given by suppliers were untraceable bad numbers, reducing the sample to 89. MAPD was in the middle of summer staff reductions resulting from summer vacations. That condition, in addition to extra workloads associated with increased sales of MAPD products, produced further delays in obtaining internal MAPD data. Final data gathering for all 89 cases was not completed until the third week in September 1985.

Data Problems

Both during and after data collection, certain problems and characteristics became evident and needed resolution by either modification of the theoretical model or the data. The problems and their resolution are detailed below.

As the data gathering took place within MAPD, it became evident that in practice at this stage of JIT development within the division data for two variables built into the model were virtually unobtainable and inappropriate. The first of these was delivery performance. While the actual delivery of product from a given supplier occurred in discrete batches, the concept used by all involved, including the purchasing system, was one of continuous flow. Much of the inventory information was handled as number of days production, and, while records could be laboriously collected to reflect delivery performance. they did not exist as part of the regularly used data base. Releases were sent to suppliers reflecting MAPD requirement for a given part on a weekly basis. The assumption was made that the delivery would be made, and no specific date was normally assigned for delivery of the quantity. It was only when the releases changed or when the inventory bank reflected a number too low for company standards did attention turn to the supplier for expediting. As a result of the difficulty of obtaining the information and the dubious accuracy once it could be assembled, it was decided that the variable should be dropped from the theoretical model for this study.

The second variable to be dropped was receiving inspection throughput time, for much the same reasons. Not only were records difficult to obtain, but the variability was very large, primarily depending on how much the parts were needed. The theoretical model assumed that when parts were received by MAPD they would be of roughly equal priority. Since the practical system was far from perfect, especially with MAPD in the early stages of changing to JIT concepts, products entering a given location were given a wide range of priorities. Some material was not needed for several days and may have not moved until needed, while other material had been expedited and was moved through very rapidly. The wide variability of potential throughput time for any given product made the variable impractical to use in the model at this stage of JIT within MAPD.

Other variables measured for control purposes turned out to barely be variables at all in the study, and can therefore provide limited insight for statistical analysis. As standalone statements, however, they provide both insight and interest in conditions of the sample.

The first of these, the only categorical variable in the study, is the method of transportation for the product. All but thirteen of the products in the sample were transported by truck. The thirteen not transported by truck were fairly well distributed between air, rail, and ship. One advantage of this condition is that delivery time should provide a fairly valid indicator of delivery distance. Distance was not built into the model nor measured in the study, as the important issues influenced by distance were delivery time and delivered lot size (both measured).

Only ten of the products in the sample had more than one supplier as the source. Of those ten, three had two suppliers, three had three suppliers, and the remaining four had four suppliers. Such a condition may appear surprising, especially since MAPD had not, by the admission of several managers in the division, progressed very far in their program to reduce the size of the supply base. The condition could, however, be at least partially explained in that the products in the sample were, by the design of the study, selected from non-commodity products (products produced exclusively for MAPD to MAPD design), as described in Chapter 3. Such products tend to be specially engineered and are apparently subjected to frequent engineering changes, making multiple sources less cost effective than for commodity products.

Upon examination of the raw data, one additional variable was expected to provide less effect in the model than hypothesized because of the relatively small amount of variability. Product quality was measured as the percentage of shipments of the part that were rejected for any reason during the previous year. This percentage was used regardless of the dispostion of the parts after rejection. Even with a measurement tactic that would theoretically include every part with even a remote possibility of a quality problem, only 41 parts had less than a 100 percent quality rating, and only 13 parts had below a 95 percent rating. MAPD had conducted an intense statistical process control (SPC) training program with its suppliers for close to three years, and this increased emphasis on product quality from suppliers may help contribute to the low variability with product quality. Even though there was a relative small variability in this variable, it was measurable and left in the model for statistical analysis. The high mean and restricted range of this variable speaks very highly of the success of the MAPD SPC program, generally recognized by many MAPD managers as the first major successful subprogram in their JIT efforts.

Missing Data

The next major data problem that needed resolution was missing or obviously incorrect data, with most of the problems centered in missing data. The only case of presumably incorrect supplier data occurred when one supplier indicated a quantity of finished goods inventory sufficient to supply MAPD at their current rate of annual demand for 259 years. Assuming that the supplier did not intend to maintain that level of buffer, the conclusion was that either the supplier inventory or annual demand figures (the two used to calculate percent of annual demand) was wrong. MAPD was contacted and the annual demand figure was reconfirmed, so the assumption was made that the supplier inventory figure was incorrect (reconfirmation of the supplier inventory figure was not possible). The possibility also existed that the supplier was using commodity data, but in either case the inventory quantity was thrown out and missing data procedures were employed.

Table 4-1 lists the total data points missing in the sample, including the incorrect inventory data. The missing data was distributed across 27 of the 89 cases.

The most appropriate method for compensating for the missing data of this type would be to regress the data using the missing variable as the dependent variable, with the missing values being filled in by predicted values from the regression equation and other case variable values. This method is described in Kalton's Compensation for Missing Survey Data (University of Michigan Institute for Social Research, 1983). When attempted, however, no combination of regression could provide better than 60 percent of the variance explained by R-squared values. As a result, these regression values did not provide enough confidence to use as a missing value technique in this study.

TABLE 4-1

SUMMARY OF MISSING DATA

Variable	Number of Missing Data Points
Information Lead Time	4
Capacity Lead Time	4
Percent Excess Capacity	4
Number of Release Changes	4
Average Size Release Change	13
Customer Inventory	8
Delivery Quantity	5
Finished Goods Inventory	4
Intransit Inventory	4
Product Quality	4
Total	44

Two primary methods were eventually employed to assign missing values. First, other cases given by the same supplier were examined. The mean of the value for the other cases from the same supplier could then be used as the missing value. This method assumes relative similarity in the conditions and data emulating from a given supplier. In situations where no data for the given supplier was available for the variable in question, or in the cases where supplier data was inappropriate (customer inventory, for example), the second procedure was employed.

The second method involved splitting the supplier sample into three basic categories--electronic, plastics, and machining. Mean values for each subsample were computed and, assuming similarities in categorical characteristics, the mean categorical values were assigned. Regression analysis was performed on the 62 complete cases and then on the 89 cases after missing value data was assigned, both using total inventory as the dependent variable. R-square values decreased from .634 to .512, indicating that the additional cases with the assigned missing values increased the unexplained variance in the model. It was nevertheless left to use all 89 cases, since the larger sample size is important for the credibility of the model.

Analysis Procedures

The basic method of examining the hypothesized relationships was multiple regression, using the continuous independent variables with forced entry and using each element of the dependent for separate regressions. The primary interest in the research was to determine the amount of variance in the dependent variables explained by the independent variables and to establish both direction and significance in the relationship between the independent and dependent variables. All of those objectives were accomplished with multiple regression. In addition, multiple regressions were performed adding the measured control variables to the reduced regressions from the first analysis to test for stability of the beta values.

Prior to regression analysis it was important to investigate multicollinearity with respect to the independent variables in the model. In order to use multivariate analysis (multiple regression) to essentially investigate univariate relationships, the assumption of no multicollinearity must be verified. Regression analysis was preferable to correlation analysis, in that the discovery of the percentage of variance accounted for by all the independent variables was important to lend support for the research model. In order to use multiple regression, however, multicollinearity with the independent variables must be investigated and dealt with should it provide a potential problem with the regressions.

The first step in the multicollinearity investigation was to examine the basic correlations between the independent variables to see if any obviously high correlations existed. Such was not the case, as can be observed by the correlation matrix in Table 4-2.

As can be seen in the matrix, correlations are relatively small in most cases. The largest (average size of release change correlated with information lead time) is only .5, and the majority are less than .2. Even so, Pedhazur (1982), recommends inverting the matrix and examining the diagonal and the squared multiple correlation of each independent variable with the remaining variables. In the absence of the ability to invert the matrix, as is the case with the SPSS package used for the statistical analysis in this study, he goes on to recommend calculating the squared multiple correlations using a formula he provides (page 237) utilizing standard numerical values from the SPSS output. Large values of the squared multiple correlations would indicate the existence of potential multicollinearity problems, and could

TABLE 4-2

INDEPENDENT VARIABLE CORRELATION MATRIX

	Supplier Manufacturing Lot Size	Average Delivery Time	Supplier Manufacturing Lead Time	Information Lead Time	Capacity Change Lead Time	Average Number of Release Changes	Average Size of Release Change	Average Delivery Quantity	Product Quality
Supplier Manufacturing Lot Size	1								
Average Delivery Time	-.20*	1							
Supplier Manufacturing Lead Time	-.12	.38*	1						
Information Lead Time	-.10	.43*	.01	1					
Capacity Change Lead Time	-.17	.15	.43	.32*	1				
Average Number of Release Changes	.15	.08	.16	-.11	0	1			
Average Size of Release Change	-.09	.18*	-.07	.50	.18*	-.15	1		
Average Delivery Quantity	.38*	0	.25*	.05*	.12	.04	.15	1	
Product Quality	.01	.18*	.35*	-.10	.34*	-.02	-.11	.19*	1

* Significant at the .05 level.

further be used to discover the potential source. These calculations were performed, using the output from the basic model (with total system inventory as the dependent variable). The results are given in Table 4-3.

TABLE 4-3

SQUARED MULTIPLE CORRELATIONS

Squared Multiple Correlation Formula:

$$R_i^2 = 1 - \frac{(1-R^2)\ F_i}{(N-K-1)B_i^2}$$

N = Sample Size
K = Number of Independent Variables

Source: Pedhazur, page 237

Squared Multiple Correlation for:

Delivery Quantity	= approx. 0
Manufacturing Lead Time	= .170
Capacity Lead Time	= .126
Manufacturing Lot Size	= .125
Delivery Time	= .098
Information Lead Time	= .051
Number of Release Changes	= approx. 0
Average Size of Release Change	= approx. 0
Quality Rating	= .114

According to Pedhazur, the low values of the squared multiple correlations indicates that each variable provides a relatively unique set of information to the model, and indicates low multicollinearity. Each squared multiple correlation gives the amount of variance in a given independent variable that is accounted for by all the other independent variables in the regression. As an example, the largest squared multiple correlation (for manufacturing lead time) indicates that only about 17 percent of the variance in that variable results from the other eight independent variables in the regression. The correlation matrix analysis and low values of squared multiple correlations indicates the lack of any serious multicollinearity with the independent variables in the regression model.

Following the investigation and resolution of potential multicollinearity problems in the regression model, the primary analysis could proceed. This analysis began with four multiple regressions, using all the independent variables with the dependent variables taken one at a time. Based on the lack of an a priori hierarchical order of inclusion of variables in the model, forced entry multiple regression was utilized, where all the independent variables were forced into the regression equation simultaneously. This same procedure was used for all four multiple regressions using total inventory, finished goods inventory (supplier), intransit inventory, and customer inventory as the dependent variables. Complete residual analysis was also completed.

After the regressions using all independent variables was complete, a reduced model regression was run for each dependent variable, using as independent variables those that provided betas statistically significant at the 0.05 level in the original regression. The new beta and R-squared values were analyzed and compared with the original regression analysis to gain possible further insight into potential key variables in the model.

A third set of regression equations were then produced by adding the control variables (supplier size, percentage of supplier sales accounted for by MAPD, etc.) to the independent variables in the reduced model. The betas in a multiple regression are partial correlation coefficients, showing the relationship between the given independent variable and the dependent variable while holding as constant the effect of the other independent variables. Since each independent variable in the original set has a very small effect on the others (as was established in the multicollinearity analysis), any major change in the reduced model would be a result of supplier characteristics established in the control variables. Analysis of any differences would provide additional insight into the stability of the key variables in the JIT model being tested.

The results and discussions of each of the mentioned analyses is the subject of the next chapter.

CHAPTER 5

RESULTS AND DISCUSSION

The data for the research was gathered and analyzed during the summer and early fall of 1985. The primary analysis, as discussed in Chapter four, consisted of forcing all the independent variables into a multiple regression with elements of the dependent variable taken one at a time. That analysis was followed by reduced model multiple regression and finally a third regression using the control variables in the regression with the reduced model independent variables. The results of the analyses is presented and discussed in this chapter.

As also discussed in the last chapter, the model was descriptive and neither causality nor predictability was hypothesized, only relationships. Even though most of the major statistics resulting from the analysis are reported in this chapter for the possible interest of the reader, the discussion is centered on the direction and statistical significance of the betas, rather than on explaining their size or value in prediction.

Regression Analysis Using Total Inventory

The first analysis conducted was forced entry multiple regression using total inventory as the dependent variable, where all the independent variables were forced into the regression. This analysis is consistent with the concept that all the independent variables have essentially equal weight in their relationship with the dependent variable.

As shown in Table 5-1, the regression produced a highly significant F value and the nine independent variables included in this initial analysis accounted for over 51 percent of the variance (46 percent in the adjusted R-square) in the dependent variable. Using a .05 probability criteria for hypothesis acceptance, a total of five of the nine variables were statistically significant. Two of them, however, (average size of a release change and the number of release changes) produced betas in the opposite direction from that hypothesized, indicating the need for in-depth discussion.

Delivery quantity provided the largest beta with the most significant F. One of the current moves in the automobile industry is to have suppliers physically closer to their customers, given the perception by industry managers that smaller quantities of inventory can only be economically moved when distances are small. If this relationship resulted from location changes, there should have been a relatively large correlation between delivery time and delivery quantity. Delivery time in this sample should theoretically be highly correlated with physical distance between supplier and customer, especially given that 76 of the 89 parts in the study were moved by the same transportation method (truck). The correlation between delivery time and delivery quantity was, however, essentially zero. Delivery time also had the smallest beta weight and smallest F value in the regression analysis.

One possible explanation of the apparent anomoly with the delivery variables centers on the stage of JIT implementation within

TABLE 5-1

TOTAL INVENTORY MULTIPLE REGRESSION

Multiple R	.71578
R Square	.51234
Adjusted R Square	.45678
Standard Error	12.16334
F =	9.22198
Significance of F	.0001

Variables in the Equation

Variable	B	SE B	Beta	F	Sig. F
Quality	-.6722	.562	-.1097	1.43	.2353
Manufacturing Lot Size	.5508	.266	.1898	4.29	.0415*
Average Size of Release Change	-.8379	.341	-.2316	6.04	.0162*
Number of Release Changes	-.2739	.135	-.1672	4.10	.0462*
Delivery Time	.0226	.078	.0298	0.09	.7718
Capacity Lead Time	-.2143	.129	-.1701	2.78	.0995
Delivery Quantity	4.2791	.805	.4978	28.24	.0001*
Manufacturing Lead Time	.3205	.097	.3474	10.82	.0015*
Information Lead Time	.6270	.387	.1767	2.62	.1093
Constant	69.4201	54.73		1.61	.2084

* = Significance at the 0.05 level

MAPD at this time. The possibility exists that changes in delivery quantities are much easier to implement than are changes in delivery method or supplier distance (major influencers of delivery time). If delivery quantity had been significantly affected as a result of forced JIT implementation while delivery time, supplier distance, and delivery method had not, then a condition such as the one observed could theoretically occur. If such was the case, then there should theoretically be a corresponding increase in load mixing, less than truckload deliveries, warehousing costs and/or freight costs. Informal supplier discussions indicated that increasing costs associated with all aspects of delivery may be taking place. The exact nature of the relationships between delivery time and delivery quantity, and their respective relationships with total inventory and transportation issues in JIT are questions that should be addressed with further research. Such research should measure delivery variables such as piece price (and transportation economic order quantities), amounts of premium freight costs, warehousing costs, less than truckload deliveries, and mixing of loads. These variables were not measured in this study, but the analysis indicates future studies of the transportation issues are warranted as JIT implementation continues to be researched.

Two other significant variables in the regression equation (supplier manufacturing lead time and supplier manufacturing lot size) were both internal characteristics of the supplier virtually out of the direct control of the customer. The existence of these significant supplier variables is interesting in that JIT literature suggests that building close supplier relationships to help suppliers obtain internal benefits from a customer's JIT project helps the entire JIT project.

Such close relationships, the argument states, will not only help the supplier but will also provide inventory reduction benefits for the customer, reducing both total system inventory and associated holding costs.

There were two significant negative relationships (average number of release changes and the average size of the rlease change) where positive relationships were hypothesized. The release change variables were intended to be measures of schedule stability, and preliminary discussions with suppliers led to the expectation that the schedule stability variables might provide strong positive correlations with inventory.

The significant negative relationships prompted informal followup discussions with some suppliers and MAPD managers in an attempt to understand the results. The general opinion was that those suppliers subjected to the largest schedule instability were also those that spent a lot of their time and energy expediting the products to MAPD. No concensus was reached as to whether the suppliers were expediting because of schedule instability or whether the schedule was unstable because of the need to expedite.

Discussions also centered on the other side of the relationship--those products with larger inventories relative to demand yet relatively stable schedules. The explanation typically offered was that many suppliers who were able to were actually increasing inventory in the system. These supplier personnel explained that MAPD was moving to reduce the size of its supply base (and, therefore, increase the demand on a given supplier). As MAPD still allowed uncertainties to exist in the schedules, suppliers often made a strategic business decision to increase buffer inventory to respond under a variety of conditions. This activity was intensified as the supply base reduction was intensified. Those suppliers who "survived" often did so based on performance, including on-time delivery and the ability to respond to customer needs. Some of these suppliers apparently accepted larger inventories as a cost of offering high customer service in view of the uncertainty they perceived as being possible, if not experienced.

These explanations are conjecture at best, and no direct statistical evidence exists to support them. The unexpected negative relationships point to additional research requirements in the area of schedule stability to measure variables dealing with expediting (i.e., premium freight, variances from production standards, splitting of lots) as well as perceptions of decision makers in the supply base concerning the nature of the changes in supplier relationships to be expected as the customer implements JIT. The fact that the explanations for negative schedule stability relationships may be true or even that they are perceived to be true by some of the people in the MAPD supply system leads to the conclusion that many changes still need to be made before the products and companies involved in this study achieve JIT as ideally presented in the literature.

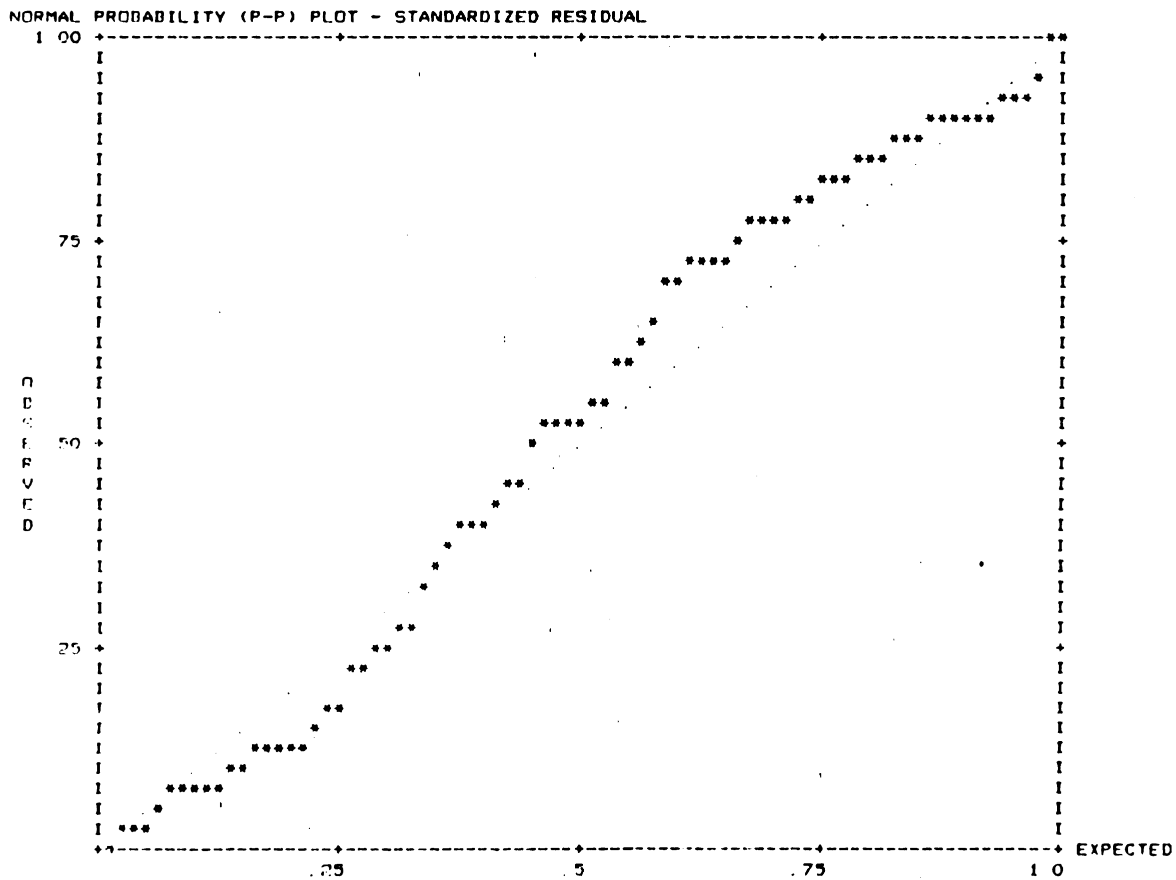
Analysis of Residuals

Four techniques were employed to examine and analyze the residuals from the regression--a casewise plot of standardized residuals, a histogram of standardized residuals, a scatterplot of residuals with predicted values, and a normal probability plot of observed versus expected standardized residuals.

The casewise plots produced an essentially random appearing pattern with ten cases producing standardized residuals in excess of 1.7, and only one in excess of 3. The raw data for each of these cases was examined to determine if any disturbing pattern or commonality was in evidence, but none was found. The histograms were very nearly normal and the scatterplots were very random appearing, again indicating no unusual or systematic trends in the residuals. Such visual inspection of the scatterplot are appropriate to indicate potential deviations from the assumptions of linearity or homoscedasticity (Kleinbaum and Kupper, 1978 and Pedhazur, 1982). The normal probability plot, on the other hand, produced a pattern worth discussion.

This plot (see Figure 5-1), tends to have observed values below predicted values on the lower end, and observed values higher than predicted on the higher end, crossing the center line just before the center point. The plot should be a straight line under conditions of normality, and any major deviations should produce suspicion of non-normal residuals. The deviations in this case provided sufficient concern to warrant further analysis of normality.

Using the categories of standard scores provided in the histogram of residuals (category width = .125 of a standard score), a chi-square goodness of fit test was conducted as an indication of normality of the residuals. The calculated chi-square value was 35.98, only slightly larger than the upper value of acceptable chi-square at the 0.05 acceptance level, 34.76. This indication of a very slight deviation from normality promoted further investigation of the residuals to determine potential problems.



NORMAL PROBABILITY PLOT OF TOTAL INVENTORY REGRESSION RESIDUALS

FIGURE 5-1

The raw data for four of the outliers that produced very large contributions to the chi-square calculation were examined. Three of the four parts were being held in large finished goods quantities by suppliers who had indicated a strategic desire to maintain large safety stocks in the face of perceived uncertainty, as discussed earlier. The forth part was one being held in large raw material stock by MAPD, for unknown reasons.

Pedhazur (1982) indicates that, as a general rule, residuals with a standard score in excess of 2 are extreme and could potentially produce an adverse affect on the regression coefficients. Neter, Wasserman, and Kutner (1985) describe the use of Cook's distance measure, D, to determine the existence of a substantial influence from an outlier. The percentile value from Cook's D can be calculated on an F distribution where, according to Neter et al., a percentage value of less than twenty percent has little apparent influence on the regression function. Percentage values of fifty percent or more, they continue, should be considered large and remedial measures should be considered. Cook's D value analysis was performed on the suspect outliers. None was found to produce an excessive influence according to Neter et al., and no remedial steps were taken.

In general, the analysis of the residuals produced no significant indications of problems in the basic model or in the analysis.

Reduced Model Analysis

A reduced model regression was run using the five variables with significant F values at the 0.05 level in order to potentially develop a better understanding of the relationships involved and the amount of variation explained. The results are shown in Table 5-2.

TABLE 5-2

TOTAL INVENTORY REDUCED MODEL

Multiple R	.67454
R Square	.45500
Adjusted R Square	.42217
Standard error	12.54488
F =	13.85872
Significance of F	.0001

Variables in the Equation

Variable	B	SE B	Beta	F	Sig. F
Manufacturing Lead Time	.2390	.082	.2590	8.552	.0044*
Average Size of Release Change	-.5670	.306	-.1567	3.438	.0673
Manufacturing Lot Size	.5705	.270	.1966	4.457	.0378*
Number of Release Changes	-.2586	.138	-.1578	3.528	.0639
Delivery Quantity	4.0804	.819	.4747	24.818	.0001*
Constant	4.8303	3.436		1.976	.1635

* = Significance at the 0.05 level

While some differences appear in the various statistical values, nothing appears that brings additional insight into the analysis or interpretation of the model with its hypotheses.

Residual analysis of the reduced model also failed to bring any additional insight or problems into the model. The chi-square analysis produced a computed value of 33.16, causing the hypothesis of normality to be accepted as compared to the 0.05 significance level for chi-square of 34.76. The visual analysis of scatterplots produced no concern of disturbing trends.

Regression Analysis Using Supplier Finished Goods

As in the case of total inventory, forced entry multiple regression was used to analyze the relationships between the independent variables and the dependent variable of supplier finished goods. The statistics are summarized in Table 5-3.

Supplier manufacturing lot size was expected to enter this regression as a significant variable, especially since MAPD was consciously attempting to limit their inventory of many of the supplied products. Under the assumption that the supplier has a lot size significantly larger than MAPD requirements for a specified time period, the remainder of the lot has to stay in the supplier finished goods. The assumption was probably valid in this sample, as many suppliers indicated during informal discussion that they had as yet made little internal changes in response to MAPD JIT implementation moves. The effect of their decision is apparently indicated in this variable relationship.

While two variables (number of release changes and average delivery quantity to MAPD) come close to being significant at the 0.05 level, no others are really close to being accepted as significant. Speculation concerning the lack of significance of the remaining

TABLE 5-3

SUPPLIER INVENTORY MULTIPLE REGRESSION

Multiple R	.58747
R Square	.34512
Adjusted R Square	.27051
Standard Error	7.24030
F =	4.62579
Significance of F	.0001

Variables in the Equation

Variable	B	SE B	Beta	F	Sig. F
Quality	-.5444	.335	-.1730	2.647	.1077
Manufacturing Lot Size	.7081	.158	.4750	20.023	.0001*
Average Size of Release Change	-.2271	.203	-.1222	1.251	.2667
Number of Release Changes	-.1459	.080	-.1733	3.284	.0738
Delivery Time	.0331	.046	.0853	.515	.4752
Capacity Lead Time	-.0299	.077	-.0463	.153	.6963
Delivery Quantity	.8493	.479	.1923	3.139	.0803
Manufacturing Lead Time	.0427	.058	.0900	.541	.4642
Information Lead Time	.0149	.230	.0082	.004	.9487
Constant	55.0994	32.58		2.860	.0947

* = Significance at the 0.05 level

variables would suggest that other variables in the model are either not as important as suggested in the hypotheses, or are not important in this sample given the size of the supplier inventory. No data exists to determine why the lack of relationships developed in the regression, but the situation suggests further research focusing on the supplier internal characteristics and responses as their customers develop JIT.

Analysis of Residuals

The same residual analyses performed on the other inventory regressions were done on finished goods regression, with much the same results concerning possible nonlinearity or hetroscedasticity. A few special comments on this residual analyses is, however, appropriate.

The casewise plot, histogram (see figure 5-2), and identification of outliers indicated a skewed distribution, with many of the cases having slightly negative residuals offset by eight rather large (standard scores greater than 2) outliers. The raw data for these eight large outliers were examined with some interesting results:

1. Six of the eight large numbers came from only two suppliers, and those two suppliers supplied essentially the same product type.

2. All of the products in the large outlier category came from the same type of industry category--not only in that they produce the same type of product but also were identified in later discussions as suppliers who wished to maintain larger than apparently necessary inventories as a strategic decision related to desired customer service level.

Further research involving industry types and/or strategic inventory decisions could potentially provide insight into whether the apparent relationships observed here are but an anomoly of the sample

```
HISTOGRAM - STANDARDIZED RESIDUAL
 N EXP N      ( * = 1 CASES,     .  :  = NORMAL CURVE)
 0   .10    OUT
 1   .05  3.00 *
 2   .07  2.87 **
 1   .10  2.75 *
 0   .14  2.62
 1   .20  2.50 *
 0   .27  2.37
 2   .35  2.25 **
 0   .47  2.12
 1   .60  2.00 :
 0   .77  1.87 .
 0   .96  1.75 .
 0  1.19  1.62 .
 0  1.44  1.50 .
 0  1.73  1.37  .
 0  2.03  1.25  .
 0  2.36  1.12  .
 0  2.69  1.00   .
 0  3.03  0.87   .
 3  3.35  0.75 **:
 1  3.65  0.62 *   .
 2  3.91  0.50 ** .
 3  4.13  0.37 ***.
 5  4.30  0.25 ***:*
 4  4.40  0.12 ***:
11  4.44  0.00 ***:*******
12  4.40 -0.12 ***:********
 5  4.30 -0.25 ***:*
11  4.13 -0.37 ***:*******
 6  3.91 -0.50 ***:**
 6  3.65 -0.62 ***:**
 2  3.35 -0.75 **.
 3  3.03 -0.87 **:
 0  2.69 -1.00   .
 3  2.36 -1.12 *:*
 1  2.03 -1.25 *.
 1  1.73 -1.37 *.
 0  1.44 -1.50 .
 1  1.19 -1.62 :
 1   .96 -1.75 :
 0   .77 -1.87 .
 0   .60 -2.00 .
 0   .47 -2.12
 0   .35 -2.25
 0   .27 -2.37
 0   .20 -2.50
 0   .14 -2.62
 0   .10 -2.75
 0   .07 -2.87
 0   .05 -3.00
 0   .10    OUT
```

HISTOGRAM FOR SUPPLIER INVENTORY RESIDUALS

FIGURE 5-2

or if the model was inadequate to explain JIT in various types of suppliers. While suppliers in this sample could be separated by industry types, the reduced samples would be too small to provide meaningful analysis.

Chi-square analysis confirms the apparent lack of normality due to the outliers. Computed chi-square was 59.28, as compared to an acceptable level of 34.76 at the 0.05 level of significance. An examination of the Cook's D values indicated that no individual score had an adverse impact on the regression, but the cumulative effect of the eight outliers apparently did. The phenomenon observed in this sample should be considered for further research into JIT implementations to determine the cause of the apparent problem with this regression and subsequently a more refined JIT model.

Reduced Model Analysis

In spite of having only one variable enter the regression with a significant beta, a reduced model was computed using that one variable. The results of that regression are given in Table 5-4.

Analysis of this reduced model produced no new insights or problems, but did continue to support the previous analysis. The chi-square analysis produced a computed value of 64.62, as compared to the maximum acceptable level of 34.76 to accept a hypothesis of normality of the residuals at the 0.05 level.

TABLE 5-4

SUPPLIER INVENTORY REDUCED MODEL

Multiple R	.51125
R Square	.26138
Adjusted R Square	.25289
Standard Error	7.32721
F =	30.78746
Significance of F	.0001

Variables in the Equation

Variable	B	SE B	Beta	F	Sig. F
Manufacturing Lot Size	.7622	.137	.5113	30.787	.0001*
Constant	1.8636	1.211		2.369	.1274

* = Significant at 0.05 level

Regression Analysis Using Customer (MAPD) Inventory

The statistics shown in Table 5-5 resulted from the regression of the independent variables with customer inventory (not yet released for production) as the dependent variable.

The fact that delivery quantity entered the equations as a highly significant positive beta should not be surprising, as classical inventory theory recognizes the relationship between delivered lot sizes and average inventory being held by the party accepting the delivery. Assuming relatively constant inventory usage and complete lot delivery, the average inventory is found by dividing the delivered lot size by two and then adding safety stock.

TABLE 5-5

CUSTOMER INVENTORY MULTIPLE REGRESSION

Multiple R	.73455
R Square	.53956
Adjusted R Square	.48710
Standard Error	8.20004
F =	10.28600
Significance of F	.0001

Variables in the Equation

Variable	B	SE B	Beta	F	Sig. F
Quality	-.0131	.3789	-.0031	.001	.9724
Manufacturing Lot Size	-.4085	.1792	-.2029	5.197	.0253*
Average Size of Release Change	-.6002	.2299	-.2391	6.813	.0108*
Number of Release Changes	-.0410	.0912	-.0360	.202	.6544
Delivery Time	.0023	.0523	.0044	.002	.9652
Capacity Lead Time	-.1212	.0867	-.1387	1.956	.1658
Delivery Quantity	3.2932	.5429	.5522	36.794	.0001*
Manufacturing Lead Time	.2664	.0657	.4160	16.441	.0001*
Information Lead Time	.49361	.2610	.2005	3.576	.0623
Constant	1.04633	36.899		.001	.9774

* = Significant at 0.05 level

What is not quite so evident is the reason for the significant relationship between supplier manufacturing lead time and inventory held by the customer, especially since the customer in this study essentially dictates the delivered lot size with the release system. No subsequent discussions were held regarding this finding, but one possible explanation is that the customer in this study had some insight into the lead time of the product and was maintaining buffer inventory to protect against timing uncertainties. Since the customer authorizes specific quantities to be released from the supplier, no other explanation for this relationship appears plausible without additional data. Designing and conducting research on this phenomenon should again be the subject of future work on JIT.

Another interesting relationship in this regression is seen with supplier manufacturing lot size. Not only was lot size significant at the 0.05 level, but it was significant with a negative beta, while it was related positively in the previous regressions using supplier inventory and total inventory. Again, only speculation can be offered for this relationship, but it might be explained under the assumption that the customer has knowledge of the lot size and the inventory of the product held by the supplier (recall that those two variables were highly related in the previous regression). With the knowledge that the supplier produced larger lot sizes and maintained larger finished goods, the customer could have recognized that a buffer existed in the supply system, making an additional buffer in the customer facility unnecessary.

A totally different argument could, however, be offered to explain the relationship. The supplier could have known that the customer maintained a smaller inventory of the specific product and therefore used larger lot sizes and finished goods inventory to maintain higher customer service in the face of anticipated schedule changes. Again, this study did not collect data to explain the relationship, but the fact that it exists in the direction that it does suggests that potentially fruitful research projects could and should be designed to explore the relationships more completely.

The remaining variable entering the equation with a significant F value was the average size of the release change. As was the case earlier, it entered the regression with a negative beta. The explanation for the negative betas with measures of schedule stability has been discussed, but only the average size of the release change was significant when related to customer inventory. Again, no data exists to explain this relationship, and further studies to examine the phenomenon in more detail are warranted.

The remaining variables provide no additional significant insights.

Analysis of Residuals

The same residual analysis that was used on the previous two regressions was conducted on the customer inventory regression. In this case, the casewise analysis, scatterplot, and histogram yielded very close to normal results (chi-square on the residuals was calculated as 32.41 as compared to a value of 34.76 as maximum acceptable at the 0.05 level) with no indications of problems of nonlinearity or hetroscedasticity. One very large outlier was observed with a Z-score of 4.78, but no special reason or relationships appeared when the raw data for that case was examined.

The one large outlier had a Cook's D of 1.08, which, according to the guidelines established by Neter et al. (1985), exceeded the recommended acceptable level. This indicated that the outlier potentially had a significant influence on the regression values. In describing possible remedial measures, Neter et al. indicated the offending outlier should be eliminated from the model only if it could be determined that the case probably represented an incorrect measurement. Otherwise, it should be retained and examined to find some explanation for the extreme value. Since no data existed to either determine the cause of the outlier or to justify its elimination, it was retained in the analysis as suggested, but with attention being called to the large influence it had on the analysis.

Reduced Model Analysis

A reduced model was run using the four variables significant at the 0.05 level. The results appear in Table 5-6.

While again providing slightly different values, the reduced model provided no new relationships or values needing further comment. The residual analysis was again very near normal, providing a computed chi-square of 26.17, well within the acceptable range with a significance of 0.05.

TABLE 5-6

CUSTOMER INVENTORY REDUCED MODEL

Multiple R	.70987
R Square	.50392
Adjusted R Square	.48029
Standard Error	8.25429
F =	21.33156
Significance of F	.0001

Variables in the Equation

Variable	B	SE B	Beta	F	Sig. F
Manufacturing Lead Time	.2303	.0529	.3597	18.924	.0001*
Manufacturing Lot Size	-.4123	.1754	-.2047	5.522	.0211*
Delivery Quantity	3.2666	.5382	.5477	36.840	.0001*
Average Size Release Change	-.4033	.1999	-.1607	4.068	.0469*
Constant	-.1707	2.12		.006	.9360

* = Significant at 0.05 level

Regression Analysis Using In-Transit Inventory

The same methods were employed in this final regression analysis using in-transit inventory as the dependent variable. The results appear in Table 5-7.

TABLE 5-7

IN-TRANSIT INVENTORY MULTIPLE REGRESSION

Multiple R	.71140
R Square	.50609
Adjusted R Square	.44983
Standard Error	1.92023
F =	8.99435
Significance of F	.0001

Variables in the Equation

Variable	B	SE B	Beta	F	Sig. F
Quality	-.1737	.0887	-.1807	3.832	.0538
Manufacturing Lot Size	.2318	.0420	.5091	30.495	.0001*
Average Size of Release Change	.0334	.0539	.0588	.384	.5370
Number of Release Changes	-.0858	.0214	-.3340	16.171	.0001*
Delivery Time	-.0060	.0122	-.0508	.243	.6236
Capacity Lead Time	-.0630	.0203	-.3188	9.640	.0026*
Delivery Quantity	.0612	.1271	.0454	.231	.6318
Manufacturing Lead Time	.1878	.0154	.1298	1.491	.2257
Information Lead Time	.0600	.0611	.1079	.965	.3290
Constant	18.9677	8.6407		4.819	.0311

* = Significant at 0.05 level

This regression produced some surprises. The first was that all three variables that emerged as significant were not expected to produce any significance with in-transit inventory. Secondly, the two variables that one would theoretically expect to be significantly related to in-transit inventory would be average delivery time and average delivery quantity. Only one of these variables indicated a positive relationship, as would be expected, and the relationships were far from being significant. Nothing in the model exists to explain these two conditions, and no speculation is offered.

After examining these results, questions must be raised concerning the validity of the measurements of the dependent variable. This conclusion is supported by the problems that many suppliers indicated when requested to provide accurate intransit inventory figures during the data gathering phase of the research. The problems they had providing the data further indicates the potentially large amount of work left before JIT is completely implemented, for the inability to easily find accurate inventory values can be considered a major source of uncertainty in the system.

Analysis of Residuals

Analysis of residuals provided no major insights, although they were slightly skewed, with most of the large outliers being positive. The computed chi-square of the residual distribution was 38.13, just slightly over the acceptable 0.05 level of 34.76. No one outlier contributed to an excessive amount of influence over the regression statistics, as indicated by an analysis of the computed Cook's D values.

Reduced Model Analysis

In spite of the possible data problems with this analysis, a reduced model regression was run using the independent variables with significant F values in the original analysis

TABLE 5-8

IN-TRANSIT INVENTORY REDUCED MODEL

Multiple R	.67016
R Square	.44911
Adjusted R Square	.42967
Standard Error	1.95510
F =	23.09844
Significance of F	.0001

Variables in the Equation

Variable	B	SE B	Beta	F	Sig. F
Capacity Lead Time	-.0556	.0161	-.2812	11.851	.0009*
Number of Release Changes	-.0856	.0209	-.3337	16.807	.0001*
Manufacturing Lot Size	.2321	.0376	.5099	38.140	.0001*
Constant	2.7294	.4593		35.309	.0001*

* = Significant at 0.05 level

As was the case in the previous reduced model regressions, no new significant insights, conclusions, or concerns appeared in this reduced model analysis. The residual analysis produced no concerns, but did provide statistically significance in the chi-square analysis for normality of the residuals. The computed value was 32.17, with the comparison value at the 0.05 level of significance at 34.76.

Regression Using Control Variables

Further regression analysis was conducted to determine if additional insights could be developed about the stability of the independent variables. As discussed in chapter four, the control variables were added to the reduced model regressions to partial out the effect of the supplier characteristics measured. The specific control variables, as discussed in chapter three, included the size of the supplier (annual sales dollars), quantity of products produced in total, excess capacity percentage, number of parts supplied to MAPD, and dollar value of sales to MAPD. An additional control variable was computed as the dollar percentage of sales to MAPD (computed as the dollar value of sales to MAPD divided by the supplier dollar sales). The effect of these control variables are summarized in Table 5-9.

As can be seen in Table 5-9, the beta values remained basically stable after the inclusion of the control variables, with the exception of manufacturing lot size in the customer inventory regression. That relationship did not hold when supplier characteristics were held as constant. The relationship was discussed in the section on customer inventory as an interesting subject for future research. No new speculation on the relationship is offered here, but the failure of the relationship to hold suggests even further the need to design and conduct future research in this area.

The analyses in general did provide several important insights into the hypothesized relationships of the descriptive JIT model, and

TABLE 5-9

THE EFFECT OF CONTROL VARIABLES
ON THE REDUCED REGRESSIONS

	Before Control		After Control	
Variable	Beta	Signif. F	Beta	Signif. F
TOTAL INVENTORY with				
Delivery Quantity	.475	.0001	.346	.0016
Number of Release Changes	-.158	.0639	-.182	.0292
Average Size of Release Change	-.157	.0673	-.124	.1185
Manufacturing Lead Time	.259	.0044	.234	.0136
Manufacturing Lot Size	.197	.0378	.272	.0033
SUPPLIER INVENTORY with				
Manufacturing Lot Size	.511	.0001	.492	.0001
CUSTOMER INVENTORY with				
Manufacturing Lead Time	.360	.0001	.330	.0013
Average Size of Release Change	-.161	.0469	-.198	.0212
Manufacturing Lot Size	-.205	.0211	-.076	.4215
Delivery Quantity	.548	.0001	.352	.0022
IN-TRANSIT INVENTORY with				
Capacity Lead Time	-.281	.0009	-.208	.0252
Number of Release Changes	-.334	.0001	-.375	.0001
Manufacturing Lot Size	.510	.0001	.496	.0001

suggested several additional research ideas. These ideas will be summarized in chapter six, together with general conclusions and implications from the research.

CHAPTER 6

CONCLUSIONS AND IMPLICATIONS

This chapter summarizes the research results and conclusions, discusses the potential implications for practice, and addresses the need for future JIT research.

Summary of the Research Results

Chapter three developed the model to be tested and presented hypothesized relationships for each of the independent variables in the model. Chapter five then presented the statistical results of the study. Prior to discussing general implications, a summary of results and implications of independent variable hypothesized relationships is presented. F-value significance in this summary are those calculated in the full (not reduced) models. In addition to the general summaries and discussions provided here, Tables 6-1 through 6-4 summarizes findings for each major regression.

1. Delivered Lot Size - The JIT model predicted a positive relationship between delivered lot size and inventory, primarily intransit and customer inventory. In general, the hypothesis was supported, as delivered lot size was significantly related to both total inventory and customer inventory. It was not, however, related to intransit inventory. Data problems may help explain lack of significance in the intransit portion of the dependent variable, as discussed in Chapter five. Effectively, the data problems indicate a violation in the basic

assumption of accurate information systems. In general, however, the results appear to support the moves by automobile manufacturers to request smaller, more frequent deliveries of purchased products as an implementation step toward JIT.

2. Supplier Manufacturing Lot Size - This variable was predicted to have a significant positive relationship with supplier finished goods. The difference between the manufacturing lot size and the delivered lot size would most likely be maintained in supplier inventory, given the assumption that the customer could dictate the size of the delivered lot size. In addition to the predicted relationship with supplier finished goods and total inventory, manufacturing lot size also demonstrated significant relationship with intransit inventory and customer inventory. The intransit inventory relationship may be explained by either the intransit inventory data accuracy problems or by suppliers shipping almost all that they make of the product as they make it. If the second explanation were true, a corresponding positive relationship between manufacturing lot size and customer inventory should result. Since a significant negative relationship (Beta = -.203) resulted between manufacturing lot size and customer inventory, the implication is that suppliers were not shipping all they manufactured above requested delivered quantity.

Manufacturing lot size moves inversely with customer inventory, implying that the remainder of the manufactured lot must be maintained in some other location, most probably the supplier's. Since a significant positive relationship between manufacturing lot size and supplier finished goods did exist, the concept of suppliers shipping the entire manufactured lot size loses credibility and again produces suspicion of the intransit inventory data. The direction of the relationships between supplier manufacturing lot size and the two inventory locations also lends strong support to the contention of many suppliers that JIT means pushing the inventory back into supplier operations.

The opposite direction of the relationships between manufacturing lot size and the dependent variables of supplier inventory and customer inventory can be further explained under the assumption that the customer has some knowledge of the supplier finished goods inventory. A high level of supplier finished goods inventory provides a buffer almost as effective as customer raw material, with a perceived cost benefit to the customer. A large lot size with corresponding larger supplier inventory would result in smaller customer inventory under the assumption of customer knowledge of supplier inventory. No other information was available to support the explanation, but the reasoning does appear to be logical with respect to JIT uncertainty and buffer principles.

Not only was manufacturing lot size related to supplier inventory, but delivery quantity was close to being related (significance of F at 0.08). This implies that at the same time larger lot sizes are related to larger supplier inventories, delivered lot sizes may also be. Suppliers with larger lot sizes were apparently shipping larger quantities yet still maintaining larger inventories in their own facilities. That relationship is supported by a positive correlation between manufacturing lot size and delivery quantity (.381). The existence of those relationships reinforces the discussion regarding suppliers who were expediting and those who were able to (and chose to) maintain larger lot sizes and inventories, as discussed in chapter five.

3. Product Quality - As discussed in chapters four and five, the restriction of range for this variable causes any relationship to lack a significant amount of credibility. The quality level was quite high (mean = 98.13) with a small standard deviation (= 2.69), leading to a conclusion that quality improvements had been the JIT element most effectively implemented within the supply base of MAPD. That finding was somewhat expected, as many managers in the division expressed pride with the significant progress the company has made with quality programs, particularily within the supply base. As indicated earlier, the general JIT model would have predicted restriction of range in virtually all the variables for a very advanced implementation of JIT.

The quality relationship closest to being significant was with intransit inventory, again bringing up intransit inventory data as being difficult to collect and perhaps not very accurate. The logic in the general JIT model would predict virtually no relationship of quality with intransit inventory, even though it would predict strong relationships with the other dependent variables. The exact opposite relationships occurred, but the restriction of range problem precludes making any significant statements about possible problems with the JIT model. The strongest statement that can be made is that the finding supports the JIT model, as the restriction of range of the quality variable is a reflection of the strong effort the division has made to improve quality. Nevertheless, the finding should be considered in design of future research.

4. Number of Release Changes - This variable, one of the two measuring instability in the customer release schedule, was predicted

to show a significant positive relationship with supplier finished goods as the supplier buffered against the uncertainty of the demand. Contrary to the prediction, the relationship was not only non-significant, but in the opposite direction of that predicted. The relationship with total inventory was significant, but again in the opposite direction from that predicted. As discussed in chapter five, a likely explanation for this finding lies in the expediting activities of several suppliers in the study and the strategic decision to hold extra buffer inventory on the part of suppliers who did not experience the need to expedite. A significant negative relationship with intransit inventory supports the expediting explanation, but the possible data accuracy problems with intransit inventory clouds the strength of the support.

Two other possible explanations can be offered, although no evidence exists to confirm them. It is possible that either the assumption of consistent management policies involving inventory or lack of independent inventory reduction programs have been violated, leading to strengthen the negative relationship found here.

5. Size of the Release Change - The previous discussion on release changes can essentially be repeated here, with a couple of exceptions. First, the negative relationship with customer inventory was significant and secondly, the intransit inventory relationship was nonsignificant, but in the predicted positive direction. The data here adds support to the possible explanations given for the number of release change results. In general, it can be said that the perception or experience of the supply base regarding the stability of the release schedule lends support to Hall's (1983) contention that JIT should be

implemented internally first, and that the JIT implementation should progress to the supply base only when the release schedules could be dependably stabilized. The apparent lack of JIT understanding in the supply base coupled with the early JIT moves to suppliers has possibly led to a result opposite from what was desired.

6. On-Time Delivery Record of the Product - For reasons discussed in chapter four, this variable was neither measured nor used in the analysis. The fact that measuring the variable was impractical, however, lends support to the argument that JIT implementation has a long way to go before it is working in MAPD as predicted by the model. Not only does the inability to gather this data produce a potential uncertainty, but it indicates an informal system of control is present, a violation of the information system assumption. Enough inventory apparently still exists as a buffer in the system to preclude calling attention to formalizing this activity to include controls for data gathering and reporting.

7. Supplier Delivery Time - Hypothesized to be highly related to intransit inventory, this variable proved to be neither significantly related, nor positively related (beta = -.006). The variable, while having a positive relationship with the other forms of inventory, continued to display very weak, nonsignificant relationships. In general, this variable lends little support to the JIT model. The prime contribution of the existing relationships was in suggesting more detailed research on the entire delivery system for JIT. It is possible that the model was unable to capture all the elements of this potentially complex issue, or it may be that the much discussed supplier location for customer JIT is not as important as the literature suggests.

Specific suggestions for research were mentioned in chapter five and will be summarized later in this chapter.

8. Supplier Manufacturing Lead Time - This variable was hypothesized to show a significant positive relationship with supplier finished goods inventory. The analysis did demonstrate that lead time was significantly related to total inventory and customer inventory, while not being significantly related to supplier finished goods. A potential explanation for this phenomenon centered on the customer recognizing the existence of longer lead times and the potential effect that a change in schedule would bring. Longer lead time items represent a higher risk in an uncertain demand environment, and, depending on the customer's perception of the ability of the supplier to react, would tend to prompt the customer to hold larger quantities of the longer lead time items in their own inventory as a buffer against the time uncertainty. Another possibility is the violation of the assumption of an effective supplier planning system. Poor planning data could provide incorrect inventory, lot sizing, and production scheduling decisions, producing poor data and results. No specific data or discussions exist to lend support to the explanations, and once again further research was suggested.

9. Information Lead Time - This variable provided little insight into the relationships tested, as it proved nonsignificant in all regression analyses. It apparently represents a relatively small amount of uncertainty for either customer or supplier to buffer against. Of all the independent variables in the research model, information lead time would probably represent the smallest uncertainty for all involved and, since previous discussions suggested a fair

amount of buffer inventory in the system for many products, little attention would probably be paid to this variable in a company's early stages of JIT implementation.

10. Capacity Change Lead Time - This variable provided little insight or support for the model, as it was not only nonsignificant (with the exception of intransit inventory, where it should theoretically should have had almost no impact), but provided beta weights in the opposite direction of those hypothesized. As with the case of information lead time, this variable would probably be considered to be one of lessor importance in comparison with the others, and would probably be ignored until the JIT implementation progresses further. The relationship with intransit inventory provides weak explanatory opportunity because of the possible accuracy problems in the intransit inventory figures. The variable should not be ignored in future research, however, as it potentially measures flexibility of the supplier manufacturing process. As such, it is part of those internal supplier characteristics which should be more completely researched in the future, as was indicated in chapter five.

11. Receiving Throughput Time - As was the case with the customer delivery records for the product, receiving throughput time was non-measurable. The variability of the measure could be very high, even with the same product being received at different times. Receiving activity was apparently prioritized according to the need of the product, and the throughput time could have a very large range due to uneven requirements of the product in question. In addition, the receiving system was apparently driven by an informal system, as MAPD managers indicated the records were not immediately available and would

have questionable accuracy if gathered. If JIT was in an advanced stage of implementation, then all products would theoretically have a very similar priority to the customer at all times, allowing for much higher validity of this measurement. Under advanced JIT implementation conditions, the need for a formal, accurate receipt information system would exist, making data gathering not only possible but also quite easy.

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TABLE 6-1

RESULTS SUMMARY - TOTAL INVENTORY

Independent Variable	Hypothesis	Beta * Result	Decision or Comment
Delivered Lot size	+	+	Accept
Supplier Manufacturing Lot Size	+	+	Accept
Product Quality	-	None	Reject
Number of Release Changes	+	-	See Discussion
Average Size of Release Change	+	-	See Discussion
Off Delivery - Number	+	None	Non-measurable
Off Delivery - Size	+	None	Non-measurable
Supplier Delivery Time	+	None	Reject
Supplier Manufacturing Lead Time	+	+	Accept
Information Lead Time	+	None	Reject
Capacity Lead Time	+	None	Reject
Receiving Throughput	+	None	Non-measurable

All Significance at 0.05 level

* "None" indicates a non-significant Beta

TABLE 6-2

RESULTS SUMMARY - CUSTOMER INVENTORY

Independent Variable	Hypothesis	Beta * Result	Decision or Comment
Delivered Lot Size	+	+	Accept
Supplier Manufacturing Lot Size	None	-	See Discussion
Product Quality	-	None	Reject
Number of Release Changes	None	None	Accept
Average Size of Release Change	None	-	See Discussion
Off Delivery - Number	+	None	Non-measurable
Off Delivery - Size	+	None	Non-measurable
Supplier Delivery Time	+	None	Reject
Supplier Manufacturing Lead Time	None	+	See Discussion
Information Lead Time	None	None	Accept
Capacity Lead Time	None	None	Accept
Receiving Throughput	+	None	Non-measurable

All Significance at 0.05 level

* "None" indicates a non-significant Beta

TABLE 6-3

RESULTS SUMMARY - SUPPLIER INVENTORY

Independent Variable	Hypothesis	Beta * Result	Decision or Comment
Delivered Lot Size	None	None	Accept
Supplier Manufacturing Lot Size	+	+	Accept
Product Quality	-	None	Reject
Number of Release Changes	+	None	Reject
Average Size of Release Change	+	None	Reject
Off Delivery - Number	None	None	Non-measurable
Off Delivery - Size	None	None	Non-measurable
Supplier Delivery Time	None	None	Accept
Supplier Manufacturing Lead Time	+	None	Reject
Information Lead Time	+	None	Reject
Capacity Lead Time	+	None	Reject
Receiving Throughput	None	None	Non-measurable

All Significance at 0.05 level

* "None" indicates a non-significant Beta

TABLE 6-4

RESULTS SUMMARY - IN-TRANSIT INVENTORY

Independent Variable	Hypothesis	Beta * Result	Decision or Comment
Delivered Lot Size	+	None	Reject
Supplier Manufacturing Lot Size	None	+	Reject
Product Quality	None	None	Accept
Number of Release Changes	None	-	Reject
Average Size of Release Change	None	None	Accept
Off Delivery - Number	None	None	Non-measurable
Off Delivery - Size	None	None	Non-measurable
Supplier Delivery Time	+	None	Reject
Supplier Manufacturing Lead Time	None	None	Accept
Information Lead Time	None	None	Accept
Capacity Lead Time	None	-	Reject
Receiving Throughput	None	None	Non-measurable

All Significance at 0.05 level

* "None" indicates a non-significant Beta

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Conclusions and Implication for Practice

One of the more interesting results from this research is that two of the independent variables (supplier manufacturing lead times and lot sizes) significantly related to total inventory were those that were essentially controlled by internal supplier activities.

A complex supplier manufacturing process could theoretically lead to both longer manufacturing lead times and a longer time required to respond to required changes in capacity (capacity change lead time). An increase in the manufacturing complexity would also suggest larger lot sizes under the assumption that setup times and associated control costs are adversely affected by increasingly complex manufacturing processes.

This argument has some support from the study in that there is a positive correlation between the two lead times. The relationship between manufacturing lead time and manufacturing lot size is not supportive of the complexity argument in that the correlation is not only weak but is, in fact, negative (-.12). The correlation between capacity lead time and manufacturing also suggests non-support of the argument with a value of -.17. Under the circumstances, it is possible that the assumption of setup time and costs being adversely affected by complexity is not valid, in that the suppliers in question have quick changeover machinery, have implemented a setup reduction program or have made a tactical decision to absorb the setup costs and opt for smaller lot sizes than economic optimization would suggest. Another possible explanation is that lead times are not associated with complexity at all, but are affected by other variables, perhaps even some type of interaction. One final possible explanation is that the

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assumptions of technological changes, capacity modifications, or effective planning systems have been violated.

Further analysis complicates relating internal supplier characteristics to the data from this sample. The complication is that the direction of the relationship between capacity lead time and all forms of inventory is opposite from that hypothesized. One explanation is that the inability to respond quickly to changes (capacity lead time) could conceivably intensify the expediting activity and lead to the negative relationship found in the capacity lead time variable as well as the measures of schedule stability.

Variables of specific internal supplier characteristics such as setup times and manufacturing complexity were not measured, as explained in chapter three. The results of this study as discussed above, however, suggest that further research concentrating on the internal manufacturing changes that occur within the suppliers as a major customer implements JIT is both warranted and necessary.

The reduced model regressions using control variables essentially supported the conclusion that observed relationships are not seriously affected by supplier differences, with the exception of the relationship between manufacturing lot size and customer inventory. While these results are not generalizable, they do seem to lend some support to the general models developed in the JIT literature. Hall (1983) is but one major author of JIT literature recommending implementation of JIT internally before working backward into the supply base, and he also suggests the importance of developing close relationships with the suppliers. These research results on supplier characteristics suggests a great deal of importance in establishing supplier linkages and in bringing the lot size and lead time advantages of JIT into that supply base of the sample. Those characteristics apparently have a great deal of impact not only on the supplier, but also on the success (measured in inventory terms) of a JIT implementation for the original company attempting to implement JIT.

As was discussed earlier, delivery time did not provide much support for the current popular view of JIT with respect to supplier geographic location, while delivery quantity did. The implication of the relationship of delivery quantity with inventory (primarily customer inventory) suggests some support for the current move in the automobile industry to try to have the supply base closer geographically to the supplied facility, allowing for the economical shipment of smaller lot sizes. Only speculation could potentially provide an answer to why delivery time did not lend support as well, but the lack of a relationship suggests the importance of further research into all characteristics of the supply base locations and delivery systems.

JIT has not progressed very far in many parts of this particular division, according to several of the managers that discussed its implementation. The evidence of the data, particularly dealing with delivery performance, receiving throughput, and schedule stability supports the contention that many changes need to be made before JIT is effectively implemented. Even in the sample environment representing an apparent early stage of JIT implementation, the results suggest that much attention and support needs to be given suppliers, and that attention should be made in a positive direction to establish close linkages to assist them in changing their own internal production characteristics, including all conditions affecting production lot sizes and lead times. Merely working with the distribution system, working with suppliers to have them move geographically closer, or forcing them to hold inventory previously held in customer raw material is not enough to bring the apparent theoretical advantages of JIT as presented in this model.

Significantly negative schedule stability measures provided the biggest surprise in the analysis, but the degree of JIT implementation and the results of informal discussions with MAPD and supplier managers are often a possible explanation as to the relationships. The apparent premature supplier involvement with inventory reduction (at the customer facility) has appeared to produce three adverse conditions in supplier facilities:

1. Apparently suppliers who cannot respond are almost constantly expediting, with schedule instability and small buffer inventories reinforcing each other. The cost of that expediting activity is unknown, but is thought to be high, and certainly not in the spirit of JIT waste reduction.

2. When possible, several suppliers apparently have made a strategic decision to hold even more inventory than usual, as they view a potential for both erratic schedules and a loss of business based on reduction of the supply base. They maintain large inventory to respond to almost any schedule change, thereby insuring a high customer service rating and their selection as a survivor in the supply base reduction activity. The cost of that excess inventory is also unknown, but again thought to be high.

3. Suppliers either don't understand the moves to JIT by MAPD or at least do not perceive the moves as being beneficial to suppliers. JIT has a bad name in many supplier facilities where the perception is that JIT will increase supplier costs. Where JIT is not understood, implementation has an additional obstacle in that suppliers feel JIT might

> be nothing more than a fad in response to a particularly bad recession in the early 1980's.

The regression analysis using control variables proved interesting in that only one relationship demonstrated a lack of stability when supplier characteristics were partialed out of the relationships. That situation implies that the results of this study are stable and largely not related to the specific characteristics of the suppliers involved. The exception to that is the relationship between supplier manufacturing lot size and customer inventory, a relationship hypothesized not to be significant by the original model.

Discussion of the Sample and Limitations of the Research

The nature of the study and the possibility of some sample bias precludes generalization, and demonstrations of prediction or causality were never intended. The model used was also very general in several aspects. All internal supplier characteristics were intended to be captured, for example, by using manufacturing lead time, manufacturing lot size, and capacity lead time. All aspects of the delivery system were measured using only delivery method, delivery time, and delivered lot size. The variables were not designed to capture detailed characteristics of the various aspects of the supply base. The purpose was to explore the supply system in this sample, speculate on the results, and provide indications and direction for future research. The future research is expected to be more detailed, specific, and perhaps generalizable. In that goal, the research accomplished its task. Nothing more should be inferred, and any attempt to generalize or make strong specific conclusions from the results should be regarded as dangerous.

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Implications for Future Research

The tested model provided some support for the theoretical models of JIT developed in the literature and in chapter three of this work. While not all the hypotheses were supported and some relationships appeared in apparently contradictory directions from those predicted, insufficient evidence appears to claim any anomolies from the theoretical model of JIT. Much more research is needed, some of which was detailed in chapter five. Those research ideas, together with other more general JIT research suggested by this study, are summarized and presented here.

1. A retest of the model is warranted, using a division of company that is generally considered to have progressed further in the JIT implementation than the one used for this research. Comparison results could both provide insight into JIT implementation and continue to provide insight into future research necessary to understand JIT in this environment. JIT in a more advanced stage might provide, for example, detailed measurements of variables not capable of being measured in this study, a larger number of significant relationships than appeared in this study, and fewer relationships existing in the opposite direction from those hypothesized. As implementation progresses toward the ideal, the variability of the data should decrease and a predictive model could be developed.

2. The testing of a model of JIT as it is implemented within the company is appropriate. Actually, "a" model is somewhat misleading, as the literature indicated a very complex and interrelated set of activities is involved in implementation of JIT. A more practical approach may be a series of specific research studies that would be

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designed to be interrelated at a later time. Certainly the literature suggests that internal JIT implementation may be as different from the Japanese experience as supply base JIT implementation is, and both the differences and the characteristics need to be studied.

3. The testing of a model of JIT as it changes the internal characteristics of the supply base of the company implementing JIT is necessary. Such a study was suggested by the research done here, as indicated by the strong relationships between inventory in the supply base and the supplier characteristics. Those characteristics need to be examined in more detail in order to possibly make more definitive and generalizable statements concerning the supply base in a JIT company.

4. The testing of JIT models as JIT is implemented and adapted by industries other than the automotive industry is warranted. The automobile industry was selected for this study for both convenience and the fact that the literature indicated that the automobile industry represented the most progressive JIT implementation in this country. What differences and similarities exist as JIT is implemented in other industries is unknown, but needs to be researched if a generalized model of JIT is to be adequately tested and supported.

5. The testing of JIT models dealing with distribution, transportation, warehousing, and physical distance between supplier and customer is necessary. Many of these concerns and issues were detailed in chapter five. In general, the results of this research indicated that many questions exist in the distribution and supply system for a JIT implementation. The potential impact of the distribution system on a JIT implementation, especially in view of the differences between

the U.S. and Japan distribution systems detailed in chapter two, warrants specific and detailed research in this area. This is research that should be given a high priority, as many companies are presently making complex and expensive location and distribution moves which may not be in the best interest of effective JIT.

6. Hall (1983) indicated possible legal problems in the U.S. with implementing JIT in the supply base as it is done in Japan. The nature and effect of these legal problems should be researched in order to design the most effective modification of JIT supply to fit the legal environment.

7. The impact of schedule stability was discussed at length in both chapter five and earlier in this chapter. The results of schedule stability in this study and the possible importance of unstable schedules on a JIT implementation warrant specific research concerning the impact of unstable schedules in all environments of industries implementing JIT.

8. Chapter five discussions implied several possible strategic impacts in JIT implementation, especially for suppliers. That discussion suggested the importance of researching the possible relationships between JIT implementations and strategic decisions of a company, both when the company in question is implementing JIT and when the companies it deals with (as either suppliers or customers) are implementing JIT.

9. According to the literature, JIT could take several years to implement in most industries, and may never be "complete." Some of the literature (i.e., Hall, 1983) also suggests that time-phased implementation steps may be appropriate to most effectively and efficiently accomplish implementation. Those statements need extensive research in

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virtually all aspects of JIT in all industrial settings. Such research would most likely be accomplished by designing and conducting a series of longitudinal studies.

The building and testing of these and other JIT models, and the integration of the findings into a tested paradigm of JIT should be expected to be a large and difficult undertaking. JIT, as the literature and the models developed from the literature suggests, is highly integrative and can be expected to cause modifications in virtually every aspect of company performance, potentially reaching far beyond those activities typically associated with manufacturing. The interrelationships and the possible interactions of the variables identified in the JIT models suggest a highly complex and difficult task lies ahead for researchers attempting to build and test a complete model of JIT.

Even so, this research is a start. Not only did the results lend support to some of the hypothesized relationships concerning JIT, but even the apparent contradictions pinpoint the need for and possibly even the direction to take for the design of subsequent research to test hypothesized explanations for the apparent contradictions.

APPENDIX

MAPD JIT SUPPLIER STUDY

The following data sheets should make providing data fairly easy and quick. Before proceeding, please note the following:

1. All data obtained from a specific supplier will remain confidential. Only myself, as the researcher, will see it. For the purposes of the study, all others (including MAPD personnel and other suppliers) will see only composite results from all participating suppliers, and individual results will not be traceable back to a specific supplier.

2. It is recognized that some data cannot be provided using exact numbers. If that is the case, close approximations will be acceptable. It is also recognized that some data, especially financial, may be considered sensitive and an individual supplier may wish to not provide it even with assurances of confidentiality. If such is the case, please provide only as much as you feel comfortable with.

3. I am asking that each participating supplier provide data for at least five part numbers supplied to MAPD, and only to MAPD. The specific parts can be selected at random by the supplier.

I again thank you for your cooperation.

Steve Chapman

Do you wish to have results of the completed study? __________

General Company Characteristics:

1. Supplier Company (or Division) size, in dollars of annual sales:

____

2. Number of Products sold to all customers:
(total finished goods part numbers)

____

3. Percent excess production capacity available:

____

Product questions (one for each product selected)

1. Product (MAPD part number) ____________________

2. Average manufacturing lot size. ____________________

3. Average delivery time to MAPD, measured from the time the supplier relinquishes control to the delivery system (even if the delivery system is owned by the supplier)

____

4. Average manufacturing lead time____________________

5. Average information lead time, measured from the time MAPD transmits data to the supplier until the supplier enters the data into their information system

____

6. Average capacity change lead time, measured as the average time it takes for the supplier to change capacity in response to the average change in release quantity from MAPD.

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7. Normal method of transportation for the product____________________

8. Finished Goods inventory quantity for the product (released from production, but not yet released for transportation)

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9. In-transit inventory quantity

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10. The number of times the product releases from MAPD have changed, within product lead time, over the past year.

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11. The average size of the release change

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