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Quantitative Modeling and Information System Support for Just -In -Time Partnership.

Faisal Badi Al-khateeb
Louisiana State University and Agricultural & Mechanical College

QUANTITATIVE MODELING AND INFORMATION SYSTEM SUPPORT FOR JUST-IN-TIME PARTNERSHIP

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by
Faisal Badi Al-khateeb
B.S., Yarmouk University, 1987
MBA., Tennessee State University, 1990
MPA., Louisiana Tech University, 1992
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ABSTRACT

Just-in-Time (JIT) supply calls for frequent, small deliveries, which arrive on time, with the quantity and quality required. For JIT to be effective there should be a cooperative relationship between the buyer and the supplier. They should work together to enhance their competitive positions in the market place. This study extends the quantitative models published in the literature to provide more realistic models for JIT operations and evaluates the costs and benefits of JIT partnerships to help in the negotiation process between the partners.

We provide a new model for the optimization of the joint total relevant cost of the buyer and supplier in the typical JIT scenario where the buyer's order is delivered in multiple shipments and the supplier's production lot size is an integer multiple of the shipment size. The new model provides more flexibility and cost saving for a JIT environment. It determines jointly the optimal values of the three decision variables: the shipment size, the number of shipments of an order, and the number of shipments per production lot size.

JIT supply requires flexible resources because of the random changes in customer demand. We provide a new model to quantify the advantages and costs of maintaining flexible resources by the JIT supplier. To avoid the high cost of flexible resources, in several cases in practice either the buyer or the supplier holds safety stock to provide the appropriate customer service level. This is the stage of transition to real JIT supply. Only the case where the buyer is holding safety stock was examined previously, we consider the case where the supplier is responsible for holding safety stock. Our safety stock model provides a valid approximation without

the knowledge of the distribution pattern of the random customer demand as long as the pattern of production follows the demand pattern according to the JIT supply agreement.

In order to aid the buyer and supplier in negotiation of a contract and improving the JIT partnership, the proposed models determine the optimal order quantity, shipping quantity, number of deliveries, and safety stock for the buyer or the supplier individually as well as jointly under different scenarios. In each case, the study compares the optimal ordering policy of the dominating party to the joint optimal ordering policy. The savings and losses for each party are computed and analyzed providing the quantitative support for negotiation, compromise, and compensation.

This study integrates operations management models both with cost accounting information systems using Activity Based Costing (ABC) and with management information systems using Electronic Data Interchange (EDI). To provide accounting data, the study specifies the cost activities, cost drivers and traceable costs of the buyer and supplier. We explore the costs and benefits that are experienced through the exchange of information between the buyer and the supplier in a JIT environment.

CHAPTER 1
INTRODUCTION

1.1 Managerial Aspects

Aggressive domestic and international competitors, high input factor prices, shorter product development life cycles, technology growth, and customers demanding better quality at lower prices have increasingly put pressure on manufacturing and purchasing managers. Globalization requires communication and coordination across time zones and locations. Time stresses drastically reduce reaction time, driving business to Just-In-Time (JIT) inventory, orders, scheduling, payments, manufacturing, and distribution (Yager, 1999). In such an environment, companies must build and maintain partnerships with suppliers who have the best overall value. Information technology (IT) enables the speedy adaptation necessary to accommodate these rapid changes. A strong linkage between companies and their suppliers is a prerequisite for high quality, manufacturing flexibility, and responsiveness to an ever-changing customer demand. In practice, however, supplier value is all too often defined solely in terms of quoted prices, without regard to the significant costs associated with ordering, receiving, and holding inventories and safety stocks.

Cooperative relationships represent a purchasing philosophy that expands the relationship with a supplier beyond that typically found in traditional purchasing methodologies. A partnership involves such elements as long-term contracts, a reduced number of supply sources, exchange of inventory and production information, and a high degree of mutual trust between the two parties. The

relationship is long-term in nature and involves close collaboration and mutual commitment.

Traditionally, buyer-supplier relationships have been adversarial. Buyers focus on obtaining the lowest priced, high quality products available and suppliers try to produce a product that meets customer specifications at the least possible cost. A lack of trust in a particular supplier leads the buyer to spread out the risk using multiple sourcing, which may depress the price of materials by playing off one supplier against the other. Such a practice may have a short-term or immediate advantage in obtaining cheaper parts and materials. At the same time, the supplier who provides the lowest price to get the bid may be willing to sacrifice quality and delivery reliability, two factors that are more critical to delivering value ultimately to the customer. Poor quality materials can lead to higher costs later as a result of spoilage, rework, and customer returns. On the other hand, late deliveries can result in stockouts and delivery problems. Therefore, this approach, although beneficial in the short-run, is wasteful over the long run (Aderohunmu, 1995).

Multiple sources are costly to maintain, simply because of the repetitive nature of the bidding process. The price-driven tactics of competitive bidding force the supplier to base their decision on short-term rather than long-term consideration, and often the outcome will be a higher product cost to the supplier and ultimately a higher price for the buyer (Landeros, 1989). Moreover, investment by the supplier in research and development and process improvement is usually limited to that which can be economically justified within the duration of the contract (Hahn, 1986).

therefore, these adversarial buyer-supplier relationships are characterized as uncertain and unpredictable.

One of the key business issues for modern corporations is the need to compress the time required to cycle orders, which involves procurement, production, and distribution activities. The Just-In-Time (JIT) philosophy applied to logistics involves minimizing the time required to source, handle, produce, transport, and deliver materials and to meet (or exceed) customer service requirements with appropriate consideration given to costs. One of the main pillars of JIT purchasing is selecting and maintaining long term contracts with a few, reliable and high quality suppliers. A desirable condition in long-term purchasing agreements in the JIT manufacturing environment is the frequent delivery of small quantities which arrive on time, with the quality and quantity required. From the standpoint of both the buyer and the supplier, the partnership is planned to be a long term, ongoing relationship. This relationship has been viewed by a number of practitioners and academicians as one key element in preparing the buying and supplier firms for the demands of world class competitiveness (Treleven, 1988).

To ensure close buyer-supplier relationships, a strong communication system should be in place. According to Heids and Miner (1992) sharing information is important to the success of these long-term relationships. An electronic data interchange (EDI) system or an internet connection is an excellent way to link the operations of the buyer and the supplier. Moreover, a cost accounting information system that provides information about the cost of activities and products is needed to enhance the performance of a JIT partnership. A new cost accounting system

known as Activity Based Cost System (ABC) has been often used. In the following sections, we first look at the concept of JIT partnerships and then examine the buyer's and supplier's perspective on cooperative relationships. We identify the benefits and the pitfalls of such a relationship. ABC and EDI will also be discussed as tools for successful implementation of a JIT partnership. Finally, we present the research objectives, contributions of the research, and the organization of the dissertation.

1.2 The Concept of JIT Partnership

JIT Partnership can be defined as the extent to which there is mutual recognition and understanding that the success of a JIT manufacturer and its suppliers depends in part on the other firm, with each firm working together and providing coordinated efforts to achieve desired outcomes from the JIT exchange. This definition was adopted from the definition of a distributor and manufacturer working partnership. (Anderson and Narus, 1990). In a JIT system, inventory is viewed as a necessary evil, frequently concealing inefficiency or poor quality. Thus, each department in a multi-step production process maintains a buffer stock just in case there is an interruption of the flow of materials from upstream departments. The JIT system allows these buffers to be reduced, theoretically to zero. In addition, the increased flexibility, or improved responsiveness of the JIT system is supposed to allow a reduction in, or elimination of finished goods inventories.

From the production and operations prospective, the concept of JIT is to produce the necessary units in the necessary quantities at the necessary time (Monden, 1981). Monden classified production control systems in two general

categories: push or pull system. Traditional production systems, such as material requirements planning (MRP), utilize a push system. Push systems project material requirements from the beginning stage of production to subsequent stages according to a predetermined plan. While traditional systems can provide economies of scale and reduce possible production disruption due to machine breakdown, poor quality items, worker absenteeism, and late deliveries are the main disadvantages of this system together with high inventory costs associated with waste.

The JIT production system, on the other hand, utilizes a demand-pull concept of production control. Each production stage withdraws just the right amount of parts from preceding stage, when they are needed (Walleigh, 1986). Suppliers are viewed as starting workstations or extended factories located away from JIT manufacturing firms. In this way, incoming materials , work in process (WIP) inventories, and finished goods can be eliminated or reduced to a minimum. Elimination of buffer stocks and tight coupling of production lines require JIT deliveries from suppliers, as well as synchronization of production stages.

1.3 The Buyer's Perspective in Cooperative Relationships

This section explains why a buyer would be interested in developing close, long-term relationships with suppliers. We outline the benefits and identify the pitfalls.

1.3.1 Single Sourcing vs. Multiple Sourcing: the Trade-Offs.

Costs are very important ingredients of both internal strategic analysis and external competitive advantages. According to Michael Porter (1996), cost leadership can be achieved only when a company has the lowest cost position in a

particular industry. A typical purchasing department has been trained to reduce the costs of components going into the final product. Its main objective is to negotiate the lowest price from vendors. This strategy focuses on quantity discounts and playing one supplier against the other to gain the lowest possible price. But, quantity discounts create excess inventory costs, and the exploitation of supplier competition results in adversarial relationships with suppliers.

Purchasers perceive multiple sourcing as a wise strategy, because if one supplier is unable to provide the parts by the due date, another supplier may be able to meet the date. Also, buyers believe that competition between multiple suppliers will result in the lowest price and highest quality products with the least variation (Ranney and Carlson, 1988). As a result, buyers regard competition to be positive. In the short run the buyers' perception may be correct; however, in the long run suppliers will be unable to change their cost structures to reduce costs and improve quality. Competition based entirely on cost may force the suppliers to cut corners and produce parts as cheaply as possible. In the short run, the suppliers may use inferior raw materials and components to remain profitable. Buyers will be unaware of this short-run strategy, because the suppliers' operations are a black box in adversarial relationships order goes into the box, the product comes out, and the buyer does not know what happens in between. Experience shows that long-run cooperative relationship costs can be reduced and product quality can be maintained or even improved (Ellram, 1995). Cutting inventory cost is the underlying motivation for establishment of this partnership.

Reducing lead times is one way that buyers can cut inventory costs. A number of papers describe purchasing strategies that reduce lead times by splitting orders between various vendors (see for example, Hong and Hayya, 1992). Since the focus in a JIT setting is to have smaller orders delivered frequently, the buyer might use several suppliers. Each supplier would be responsible for delivering a shipment at regular intervals. With multiple suppliers, the number of actual orders placed may not increase, since the same orders would have to be placed irrespective of supplier numbers. The shipment costs may rise with shipments from many different locations. With different suppliers, the variability of component quality may increase due to differences in processes and equipment. Managing multiple suppliers may be more difficult than simply working closely with one. However, if the buyer invests the time necessary to make these relationships highly cooperative and long term, many of these problems will disappear. Many synergetic benefits can be experienced with these partnerships.

As mentioned earlier, long-term buyer-supplier relationships may result in many synergetic benefits. Suppliers may be more willing to provide flexible delivery schedules, to deal with unusual requests, to help with the customer's product design, and to emphasize the supply of quality parts. To offset the potential risks of working closely with a supplier, buyers must take special care to select suppliers who will work well with them. An empirical study by O'Neal (1987) on the implementation of JIT in the automotive industry found that the single-sourcing approach is being used more frequently and that buyers are selecting suppliers with more care.

1.3.2 Competitive Advantages for the Buyer

Buyers that work to establish cooperative buyer-supplier relationships can gain a competitive advantage. Lyons (1990) outlines the main advantages and disadvantages for the buyers and suppliers who enter into partnerships. Buyers will experience reduced manufacturing and labor costs, improved quality, and enhanced control through predictability. Quality will improve because the supplier, most of the time. is more technically oriented than the buyer and items will be closer to specification, since there are only a few key suppliers for a given product. Purchasing will be easier to manage because the buyer would need to focus on fewer suppliers and fewer transactions. The use of electronic data interchange (EDI) system further simplifies and enhances buyer-supplier communications.

In addition to that, buyers can assure fair pricing, because the cost structure of a supplier can be revealed and price reductions can be included in the contracts. Sriram (1990) states that " the long term collaborative relationships offer cost saving and more flexible use of assets, without fear of nonperformance or opportunistic behavior by suppliers".

The buyer may decide not to manage its own inventory; the buyer can simply allow the supplier to be responsible for timely replenishment (Brown, 1994). The buyer can provide suppliers with its requirements and allow them to determine how much to send and how often to send it. This approach further reduces the usual order placement requirements of the buyer and increases the supplier's manufacturing options.

1.3.3 Possible Drawbacks for the Buyer

As with any strategic choice, these cooperative partnerships may have certain problems. The buyer may become too dependent on suppliers and may lose essential core skills to suppliers. Indeed, the supplier may gain enough of those skills to be able to compete with the buyer in its own market. In addition, the buyer may need to be concerned about reduced supplier competition. In the long run, these relationships may become barriers to competition thereby reducing the number of suppliers in the market. As a result, the buyer may become increasingly dependent on the supplier. Finally, since the search for potential suppliers is very important in a cooperative environment, the costs of supplier selection and maintenance may increase.

1.4 The Supplier's Perspective in Cooperative Relationships

This section explains many of the benefits that a supplier may gain from entering into cooperative agreements with buyers; the possible disadvantages are also discussed.

1.4.1 Advantages for the Supplier

Several studies show that one of the major motivators for suppliers to implement JIT partnerships is to secure a reliable market. Long-term contracts guarantee business as long as the supplier meets the delivery terms. Some studies found (Ellram, 1995) that the average number of years that a partnership is expected to last would be 8 years and 16 years from buyer and supplier perspectives, respectively. It is not surprising that suppliers are hoping the partnership will last longer than buyers do because the supplier is entering the partnership to secure reliable markets and to improve forecasts of demand requirement. Long-term

contracts provide greater demand certainty, larger market share, and an incentive to invest in product /cost improvement programs over a longer term. Moreover, by signing a long term contract, the supplier can stabilize its short-term production schedule, and can also have a strong basis for planning long term capital expenditure that may improve cost efficiency and permit further price reduction.

The relative demand certainty allows the suppliers to dedicate a portion of the firm's resources to meet this demand. By doing so, suppliers will benefit by having fewer slack resources. This security for the supplier justifies investments that result in a reduction of production and setup cost. On the other hand, the long-term nature of this strategy provides the buyer with leverage in controlling prices, quality, delivery lead-time, and an overall lower cost per unit.

Moreover, suppliers who become involved in these long-term relationships will have strengthened buyer support (Ellram, 1995). Research and development becomes more focused because the supplier will know exactly what the buyer needs. The supplier may have inside information about influential people in the buyer's organization and about their future buying decisions. Such information can give the supplier a competitive advantage when attempting to secure additional contracts with buyers. Suppliers will also experience a reduction in the variability of the buyer's orders, which yields easier production scheduling (Turnbull, 1992)

Champan and Carter (1990) show that a strong relationship exists between the supplier's inventory level and its manufacturing lot size. Suppliers hold larger inventory quantities when their manufacturing lot sizes are large. They do not ship the entire lot to the customer, but hold on to part of it to meet future orders. To avoid

the disadvantage of having to hold inventory to meet the buyer's delivery schedule, the vender should concentrate on modifying its production plan. With the proper changes, the supplier should be able to schedule production so that it can complete a batch of components according to the buyer's demand pattern. If the buyer and supplier are linked via an EDI system, as in many cooperative relationships, the supplier can directly monitor the buyer's inventory level and schedule production based on the observed inventory depletion rate. The use of EDI in such a partnership will be explored in a subsequent section.

By gaining access to information about the buyer's inventory level, a supplier can become more aware of and more responsive to the buyer's needs. Direct monitoring of the buyer's inventory level can reduce supplier lead-times for those components. Production scheduling can be smoother with fewer disruptions due to fluctuations in buyer's demands. Without this information, a supplier must increase the amount of finished goods inventory, increase the production capacity, or forego sales when they are unable to meet demand (Primrose, 1992).

In addition to improved demand information, the supplier's competitive position may also be improved just by being a partner. Partnering builds customer loyalty and raises the entry barriers for other supply sources. Raising the barriers to entry sustain the supplier's profit margin. If other firms can easily enter a market, the current profit margin realized by supplier could diminish. Therefore, if the firm is a strong partner to the biggest buyers, other companies may be deterred from competing in that market. Partnerships may help the supplier establish global operations. Suppliers can seek buyer partners in other areas of the world where they

are interested in doing business. Often, it is difficult to establish operations in a foreign country, but by partnering, the supplier can develop contacts to helping understanding local customs and regulations (Primrose, 1992).

All of the benefits mentioned will result in long term cost saving. Suppliers in such cooperative alliances experience benefits unattainable in short-run, lowest price competition. In the long run, it will be less expensive for suppliers to retain existing customers than to develop new customers. The supplier's marketing research can be decreased because much of the information about future buyer needs and rival firms can be obtained from the buyer-partners. The cost of holding inventory will go down since the uncertainty in demand partners will be moderated.

1.4.2 Possible Disadvantages for the Supplier

Suppliers are perceived to be at a considerable disadvantage in partnerships. The supplier could be at a buyer's mercy if the relationship is not mutually beneficial. The supplier could be requested to disclose its cost structure, which could cause concern about proprietary information being leaked to competitors. Once the supplier's cost structure has been revealed, the buyer could use the information to take advantage of the supplier either by asking the supplier to accept a smaller profit margin or by using the information to get a lower price from a competitor.

Suppliers involved in partnerships may need to held additional inventory to meet the buyer's delivery requirements, especially if the buyer does not help the supplier revising its system to meet shipment dates in a reasonable manner (Cheng, 1993). When a supplier establishes an exclusive relationship with a buyer, the company is usually required to sign a contract. This contract describes the types of

services the supplier agrees to provide and describes the penalty if it is unable to meet the promised obligations. To ensure that no penalties are incurred, the supplier may have to make an extra effort to meet that buyer's demand. The supplier may have to interrupt its production schedule to make the necessary products, hold extra inventory, or expedite the buyer's orders. These actions all come at an extra cost to the supplier, for the supplier may have to backorder production for other regular customers, incur overtime costs to meet total demand, or pay for extra storage for products that are produced in advance. All these issues are important in modeling the costs and benefits of cooperative relationships.

1.5 Joint Benefits of Adopting JIT by the Buyer and the Supplier

Costs are very important ingredients of both internal strategic analysis and external competitive advantages. According to Michael Porter (1996), cost leadership can be achieved only when a company has the lowest cost position in a particular industry. When the buyer and supplier enter into a JIT partnership, both of them benefit from cost reduction.

In a study (Ellarm, 1995) that surveyed the purchasing organizations of more that 300 Fortune 500 firm's purchasing organizations found the main reasons buyers and suppliers enter into a partnership. The reasons, buyer's and supplier's perspective are ranked Table 1.1. The study found out that the average number of years that a partnership is expected to last would be 8 years and 16 years from buyer and supplier perspective, respectively. It is not surprising that suppliers hope the partnership will last more than buyers do because the supplier is targeting from the

partnership to secure reliable markets and to improve forecasts of demand requirement.

Table 1.1
Main Reasons Buyers and Suppliers Entered into Partnership

	Buyers Perspective	Suppliers Perspective
1.	Obtain a better price or minimize total cost for the purchase items	Secure reliable market for this item
2.	Secure a reliable source	Desire to influence customer quality
3.	Desire to influence supplier'quality	Support customer JIT initiative
4.	Desire to improve delivery schedules	Desire to improve forecast of requirement
5.	Desire to influence /gain access to supplier's technology	Reduce ongoing administrative procedures and costs for ordering, invoicing, etc.

The most interesting difference between buyers and suppliers partnering impetus relates to the pricing aspect of the partnering the arrangement. Price/total cost was the key driver for buyers to form the partnership. However, suppliers appear not to be as concerned with the price received as they are with having reliable demand, influence on customer's quality, improving JIT, and obtaining better requirements forecasts. Even though, the supplier must meet the buyers frequent delivery policy, there will be an additional inventory holding cost to the supplier for keeping safety stocks. Hence, suppliers are seeking a long-term contract with buyers to compensate for their losses.

1.6 Activity Based Costing System and JIT Partnership

One of the major problems associated with JIT models that are developed in operation management is the lacking of appropriate cost data to quantify the costs and benefits of implementing a JIT partnership. In most cases, a traditional costing system has been applied to collect such data. Since this method does not have the

ability to keep track of all cost items that are associated with inventory costs, new method emerged in the early 90's called activity based accounting system (ABC).

Activity-Based Costing, as the name suggests, traces the cost to the cost objects (products, customers, etc.) through activities. This is in contrast to traditional cost accounting, which traces costs directly to products. Activities, rather than products, consume resources and the demand for those activities in the manufacturing process determine how the costs are allocated to the individual cost objects. Resources include all the costs recorded by the accounting system in carrying out daily business, such as salaries, materials, overhead (rent utilities, insurance, advertising, etc.). Activities are procedures that are carried out in order to manufacture a product or provide a service. The business process can be broken down into activities. Typically, activities are grouped by function and the grouping is referred to as an activity center. Cost objects are the final result of the business process.

Using an ABC will improve information about the cost of activities, because activities are poorly defined in a traditional cost system. Traditional cost systems use only unit level cost drivers. In the opposite, ABC reports more accurate product costs because it uses several different types of cost drivers. It allows decision-makers to accurately trace overhead and to determine the real causes of overhead. This information can be used to eliminate or improve activities that consume excessive amounts of overhead. Under the JIT philosophy, there are some activities that are unnecessary to do, such as, to inspect the parts when they are delivered by the vendor, and to place the parts on the shelf in the stockroom. Eliminating these

activities reduces the overall cost and the cost of the products that no longer use these activities. ABC provides a good estimate of the cost of eliminated activities. The cost of inspection activity, for example, is likely to be identified separately. If inspection activity is eliminated, the ABC system will reveal both the overall reduction in cost and the specific source of the cost reduction. On the other hand, a traditional cost system is unlikely to reveal the potential cost savings that come from eliminating activities. The cost savings are typically buried in large overhead pools that do not reveal the source of cost reduction. Therefore, improved information about the cost of activities and products facilitates the cost reduction objectives of continuous improvement by allowing managers to stimulate the cost consequences of decisions that change the performance of the use of activities. In summary, ABC is superior to the traditional costing system in reporting the cost consequences of these actions (Turney, 1991). We will examine the impact of ABC on JIT models, more specifically, the effects on the cost parameters and the negligence of indirect costs of inventory are considered in subsequent chapter.

1.7 Electronic Data Interchange for Information Exchange

To ensure buyer-supplier partnership, a strong communications system should be in place. An Electronic Data Interchange (EDI) system is an excellent way to link the operation of the buyer and supplier. An EDI system is a formal computerized link between the buyer and the seller facilitating business communications and transactions. Functional areas, such as engineering, production, logistics, purchasing, and sales, can be cross-linked via the EDI system. The benefits of EDI include: reductions in paperwork, personnel, inventory costs, and order lead-

time (Wang and Seidmann, 1995). Basic order placement and payment transactions can be dramatically simplified with this system. Not only will an EDI speed up operations in purchasing and delivery, it will dramatically reduce errors. Error reduction can save the time spent correcting them and the money spent on clerical costs and overcharges (Sadhawani and Sarhan, 1987).

Although the initial investment such a system is large, the long-term cost savings and reduced planning complexities will ultimately offset the expense (Anvari, 1992). An EDI system can relay valuable inventory information from the buyer to the supplier by providing access to the buyer's inventory monitoring system. The supplier should be able to schedule its production more effectively by observing changes in the buyer's inventory level. The supplier's objective may be to complete the buyer's order in time for shipment and consequently avoid holding excess components to meet the buyer's future delivery schedule. Wang and Seidmann (1995) show that when the benefits the buyer experiences from the installation of EDI systems are high it is in the buyer's interest to subsidize the supplier's adoption of an EDI system. The use of an EDI system and the establishment of a cooperative buyer-supplier partnership make the implementation of a JIT delivery schedule much easier. The use of EDI systems to link the supplier and buyer will be explored further in subsequent chapters.

1.8 Research Objectives

The objectives of this study are: 1) To extend the quantitative models published in literature, so that they can be used by the buyer and supplier in negotiation and cooperation in a JIT partnership, 2) To provide numerical solutions,

sensitivity analysis, and managerial analysis of the JIT partnership models under different scenarios for decision makers, 3) To provide accounting data that specifies the cost activities, cost drivers, and traceable costs of the buyer and supplier, and 4) To explore the costs and benefits that are experienced through the exchange of information between the buyer and the supplier in a JIT environment.

1.9 Contributions of the Research

Economic order quantity models, which are adjusted for multiple deliveries (Pan and Liao, 1989, Ramasesh, 1990, Fazel 1997, and Kim and Ha, 1998) or consider the cooperation between the buyer and supplier (Banerjee, 1986, Goyal, 1988 and Miller and Kelle, 1998) have been published in the literature. The JIT philosophy emphasizes both of these elements. All of the proposed models published in the literature have addressed two scenarios. The first scenario, where the order quantity equals the production lot size. More specifically, the number of shipments per order is equal the number of shipments per production lot size. The second scenario, where the shipment size equals the production lot size. We provide a new model for single sourcing where the buyer's order is delivered in multiple shipments and the supplier's production lot size is an integer multiple of shipments assuming the number of shipments per buyer's order quantity can be different from the number of shipment per production lot size for the supplier. This new extension is more realistic and it can provide more flexibility in choosing the appropriate lot size for the supplier. We expect that it can result in a cost savings overall. These models consider a deterministic environment. Under JIT supply, ideally, the buyer and supplier operate in a deterministic environment, neither the buyer nor the supplier

has to hold safety stock. There is always uncertainty in the customer's demand, but flexible resources and short production and supply lead times enable the required service level to be met in this case without holding safety stocks. In practice, however, the appropriate flexibility and capacity are not available or they are too expensive to maintain. We call this stage the time of transition to JIT supply. For this stage, either the buyer or the supplier has to hold safety stock to provide the appropriate customer service level. Only the case where the buyer is holding safety stock was examined previously *(Kelle and Miller, 1998). We provide a new case* where the supplier is holding safety stock in the transition stage to JIT. In the spirit of JIT, the study finds the minimum safety stock needed in order to protect against shortages that may be caused by delivery delays or excess demand. The safety stock that is required to provide the appropriate customer service level depends on the number of shipments and on the shipment size. The proposed models determine the optimal values of the three decision variables, the shipment size, the number of shipments and safety stock jointly.

In order to aid the buyer and supplier in negotiation of a contract in a JIT partnership, the proposed models determine the optimal order quantity, shipping quantity, number of deliveries and safety stock for the buyer and the supplier individually as well as jointly under different scenarios. In each situation, we consider three typical cases in our managerial analysis which are: supplier's dominance where he chooses large production lot sizes and shipment sizes; buyer's dominance where he chooses frequent shipments of small size; the case where the buyer and supplier have equal power in negotiation. In each case, the study compares

the optimal ordering policy of the dominating party to the joint optimal ordering policy and provides a quantitative tool for negotiation between the parties. The savings and losses for each party are computed and analyzed providing the quantitative support for negotiation, compromise, and compensation.

One of the major problems associated with JIT models that are developed is the lack of the appropriate cost data to quantify the costs and benefits of implementing a JIT partnership. To provide accounting data for evaluating the costs and benefits of JIT partnership, in the study specify we the cost activities, cost drivers and traceable costs of the buyer and supplier using an Activity Based Costing System (ABC). We explore the costs and benefits that are experienced through the exchange of information between the buyer and the supplier in a JIT environment.

1.10 Organization of the Dissertation

The study consists of six chapters: Chapter 1 is an introduction, discussing the purpose of the study and the basic managerial problems. Chapter 2 reviews the relevant literature on the relationship between buyers and suppliers in a JIT environment including the EDI and the ABC literature. In Chapter 3, quantitative models are presented that extend the results of deterministic and safety stock models found in the literature. We quantify the major costs and benefits resulting from entering a JIT partnership. The models are presented from the buyer's and supplier's perspective and the joint benefits of a partnership are quantified. Chapter 4 presents numerical solutions, examples, and sensitivity analysis followed by a managerial analysis of the JIT partnership in different situations. The results of numerical investigations on the effect of different factors, estimation errors, and the tendencies

in a JIT partnership are then summarized. Chapter 5 examines the impact of ABC and EDI on JIT models through the cost parameters. We show how critical the assumptions of a cost accounting system are to the formulation of JIT partnership models. The study examines how the impact of JIT on these activities can be evaluated based on ABC. To provide accounting data, the study specifies the cost activities, cost drivers and traceable costs of the buyer and supplier. The study further examines the case where the buyer and supplier are in a cooperative relationship with JIT deliveries and an EDI or internet connection. Chapter 6 offers concluding remarks and discusses the limitations and future research directions.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The previous chapter discussed the potential costs and benefits of buyer-supplier relationships from a qualitative managerial point of view. This chapter reviews the literature on JIT partnerships and other related subjects such as ABC and EDI. The organization of this chapter is as follows: Section 1, reviews the descriptive and survey-based literature on JIT partnerships. Section 2 deals with quantitative papers related to JIT Partnerships under different situations. The results of cooperative buyer-supplier models toward JIT are summarized in Table 2.1. The reviews of ABC and EDI literature related to JIT are presented in Section 3 and 4 respectively. Finally, Section 5 provides some comments on the available literature on JIT partnership and suggests research opportunities.

2.2 Review of Descriptive and Survey Based Literature in JIT Partnership

Many papers discuss the costs, benefits and implementation of JIT Partnerships. Such as Champan and Carter (1990), Sriram (1990), Primose (1992). In a study (Ellarm, 1995) that surveyed more that 300 Fortune 500 firm's purchasing organizations found the main reasons that buyers and suppliers enter into JIT partnerships from each one's perspective and ranked them. She found that price/total cost was the key driver for buyers to form partnerships. However, suppliers appear not to be as concerned with the price received as they are with having reliable demand, influence on the customer's quality, improving JIT, and obtaining better requirements forecasts. Billesbach, Harrison, and Croom-Morgan (1991) compare

JIT Purchasing activities in the U.S. and the U.K., whereas, Giunipero and Keiser (1987) compare JIT in manufacturing and non-manufacturing environments with the use of a case study.

Ramaparu, Mehra and Frolick (1995) summarized the general results of this type of research in an overview of 105 in JIT adoption studies, in which all of the 25 empirical papers listed were surveyed studies. The general results from the review of these studies are that the successful JIT implementation factors included buyer-supplier partnerships, management commitment, and production strategies.

2.3 Review of the Quantitative Literature

Most of the models that quantify the benefits of buyer-supplier cooperation use the basic Economic Order Quantity (EOQ) relationship as a foundation for model building. This section will review three scenarios: first, the cooperative models without JIT partnership; second, JIT partnership models that considers only the deterministic situation; finally, JIT models that extend the deterministic case by incorporating the safety stock into the model.

2.3.1 Cooperative Models Without JIT Partnership

In traditional buyer-supplier relationships, buyers periodically send orders to suppliers. Buyers may order their economic order quantity (EOQ), which balances a buyer's inventory holding costs with its ordering costs. When the buyer's ordering cost is low, implementing an EOQ solution will result in frequent orders of small quantities. Suppliers, on the other hand, face a different economic balance. They must balance setup costs and the cost of holding finished goods to meet the buyer's demand. When suppliers' setup costs are high, an economic balance would call for

large production runs. If the buyer is the more powerful partner, the supplier holds excess inventory or does many setups to satisfy the buyer's orders. If the supplier is the more powerful partner, the buyer will be forced to place larger orders and therefore hold more inventories.

Goyal (1976) combines the buyer and supplier inventory costs and he formulates a joint model to reflect the combined costs of the two parties. The model finds order placement interval for the buyer, which minimizes the joint variable cost per unit time. Goyal shows that, in isolation, partners will minimize their own individual variable costs. The sum of the variable costs in these independent plans is higher than the sum of the variable costs in the joint solution.

Banerjee (1986a) develops a joint economic lot size (JELS) model. His paper discusses a buyer supplier relationship, where the order quantity is the one that results in lower joint costs. This joint model is a combination of the two parties' EOQ models. Depending on which party received the cost benefit when optimizing through price reductions by the supplier or through price incentives established by the buyer. Banerjee proves that the JELS solution results in a lower system-wide cost than either individual optimal solution. In another paper, Banerjee (1986b) studies the pricing decision of a supplier interested in obtaining a specific profit on its product. If the supplier wishes to meet a given profit goal, it must set a price that encourages the buyer to place orders of the proper size. Again, this model is based on an EOQ formulation. However, this model requires the supplier to estimate accurately the buyer's holding and ordering costs, and these costs must be known to set the appropriate price. The model ignores the joint benefit issues that occurred from the

cooperative relationship; it only specifies a supplier's strategy to reach a particular profit from a given buyer. Also, the model does not include shipping cost hence, it assumes to be constant.

Goyal (1988) provides a more general joint economic-lot size model than the one presented in Banerjee (1986a). He allows that the producer could produce in lot sizes of nQ, where Q is the buyer's order quantity and n is an integer. The model is shown to provide a lower or equal joint total relevant cost as compared to the model of Banerjee. Once again, one of the major limitations of this model is the assumption of deterministic demand and lead times, where as in real life, both of them are random variables.

Some attempts have been made to establish a link between EOQ models and the JIT philosophy. D'ouville et al. (1992) develop an economic production quantity (EPQ) model. Their model is based on the premise that the production rate and production run length (replenishment time) can be determined by the vendor and that the manufacturing lot size is simply the product of the production rate and the replenishment time. Instead of the usual choice of a production quantity size, the vendor can choose the production rate and the length of the production run independently. This model shows that the total holding cost goes to zero as the production rate approaches the demand rate and the replenishment time becomes longer. Under the D'ouville et al model, the buyer experiences JIT, but the supplier is dedicated solely to meeting the buyer's demands.

Goyal and Golpalakrishnann ,(1993) criticize the D'ouville et al. (1992) paper. They show that controlling the production rate and the production run length

was not the way to reduce the lot size. In fact, the supplier should control the production rate and lot size in order to institute a JIT setting with the EPQ model. The production run should not be treated as an independent variable, as in D'ouville et al. (1992), because run length is determined by lot size and the production rate. The authors develop a model providing the optimal production rate given different cost ratios. From the optimal production rate, the optimal lot size can be determined.

2.3.2 JIT Partnership Models under a Deterministic Environment

There are few quantitative JIT purchasing models available in the literature. Pan and Laio (1989) develop a single EOQ type model for a JIT delivery system. In a traditional EOQ model, it is assumed that the demand rate is known and constant, the unit cost is independent of the order size, there is a constant rate of items from inventory, and orders are received instantaneously. In order to determine the optimal order quantity, the sum of the ordering and holding costs are minimized. Pan and Liao extend this model, to the situation where the order is split into equal parts. It is assumed that there is a long-term partnership between the buyer and supplier, and that the number of deliveries does not affect the ordering cost.

Ramasesh (1990) extends this model by adding a shipping cost to the total relevant cost and suggests that it "will enable us to achieve savings in cost and motivate our move toward the ultimate form of JIT purchasing." These models consider multiple deliveries of an order, but they only consider the purchaser's costs and no co-operation, which should be emphasized in JIT purchasing.

Golhar and Sarker (1992), develop an inventory model from the supplier's point of view. Their model considers inventory both on the raw material side and on

the finished goods side. The model is unique in the sense that it looks at shipment size, the number of shipments during the inventory cycle, and the number of shipments during the production run. Two different solutions are given: one where the length of the production run and the cycle time are integer multiples of the time between shipments, and a second where the time between shipments is not synchronous with the production run length or cycle length. Shipment cost was not considered in the model, therefore, their results indicate that the inventory costs of the company decrease linearly with shipment size. Sensitivity analysis shows reductions in setup costs and holding costs result in nonlinear fractional savings in total costs. Therefore, potential investments in new processes and technologies to reduce either setup or holding cost can be evaluated by calculating the corresponding expected percentage decrease in total costs.

Aderohunmu et al. (1995) examines a JIT co-operative batching policy with an open exchange of information between the buyer and the supplier. Banerjee and Kim (1995) include the raw material supply in the producer's and buyer's total cost in an integrated co-operation model. Their model assumes that the demand rate, production rate, and delivery time is constant and deterministic.

Fazel (1997) formulates a mathematical model that compares the annual cost of inventory for JIT and EOQ purchasing. The model establishes an upper limit for the purchase price of any item under JIT, above which JIT will be more costly than EOQ. The idea is that, the determination of price level provides a basic ground for negotiation between buyer and supplier.

Kelle and Miller (1998a) provide a JIT joint economic order quantity model that can help in quantifying the compensation level in the negotiation process. The proposed model minimizes the sum of the total relevant costs for the buyer and the supplier, as a compromise in contract negotiation. If the supplier and buyer are equally strong, the joint order quantity can be used as compromise. When we have unbalanced power between parties, the weaker party can encourage the other party to agree to the joint optimal order quantity by offering compensation for the loss he will incur. These models consider only the deterministic situation, which is unrealistic, especially during the transition to JIT.

Seung and Dac (1998) develop an integrated JIT lot-splitting model that determines the optimal order and shipping quantities over a finite-planning horizon. There model focused on the integrated total relevant costs of both buyer and supplier and shown that the policy of frequent shipment in small lot size result in less total cost than single shipment policy. Similar to Kelle and Miller (1998a) the model was limited to a relatively simple JIT environment, single buyer single supplier, under deterministic conditions for single product.

2.3.3 JIT Partnership Models under an Uncertain Environment

There are very few quantitative JIT purchasing models available in the literature that considers random demand and random lead-time with multiple deliveries because of the difficulty in developing mathematically tractable models. Kelle (1984) provides models to find the minimum safety stock for a prescribed service level where the multiple delivery times are random and the demand is deterministic. Kelle and Schneider (1992) extend the above results to model the

multi-stage production process. They approximate the minimum work-in-process inventory target level needed to provide a prescribed service level. Chapman (1992) presents a procedure for the effective use of inventory in a risk-averse JIT implementations and for systematic process improvements to allow moving toward the "ideal" JIT environment. The procedure described allows a manufacturing firm to pursue the highly beneficial continual process improvement associated with JIT but allows that activity to occur without the customer-service or processing – interruption risks associated with the identification of the process problem in a JIT setting. Pagell et al (1998) present three case studies of companies in the same studies to validate the relationship between uncertainty, flexibility and safety stock in the context of JIT environment. The results indicate the complex interdependency of the various factors involved. Using an EOQ-based model, Natarajan and Goyal (1994) concluded that safety stocks are still necessary under JIT. This result is derived from the fact that JIT Purchasing increases the number of orders placed per period and thus the number of possible stockouts increases. The authors concluded that organizations might need to consider safety stock levels as lot sizes fall under a JIT system. Kelle and Miller (1998b) extend the deterministic JIT buyer-supplier model by incorporating the safety stock expression as given in Kelle (1984) into the joint total relevant cost. Three models were presented considering random delay in shipment, random yield and random demand rate. The first model assumed that the optimal safety stock depends on the decision about the order quantity and number of shipment. Thus, in calculating the optimal quantity (Q) and number of shipment (n), the safety stock must be considered also. The authors extended the first model by

considering the case where we have delay in delivery. Quality problem can also arise. This model based on the assumption that the effective quantity may be reduced because of defective items that cannot be used. The first two models presented in Kelle and Miller (1998b) have assumed that the demand rate is deterministic. The authors present and extension to the second model where this assumption is relaxed to assume that the demand rate is random at the time of the contact. These models will be discussed and analyzed in detail in Chapter 3.

2.4 Review of ABC Literature Related to JIT Partnership

The Concept of Activity-Based Costing (ABC) has been prevalent in accounting journals since the late 1980s when it was defined and popularized. Since then, hundreds of articles have been written on the subject, mostly in business journals, the majority of them being either of a descriptive nature or case studies. Relatively few articles have explored the implications of ABC on areas outside product costing and process improvement and even fewer have ventured outside the field of accounting to look at the effect of ABC on Operations Management models.

In the early 1980s articles began to appear in the literature highlighting the problems with the traditional product costing and formalizing the concept of ABC. Miller and Vollman (1985) describe a " hidden factory" that incurs overhead costs that are not controlled by the cost accounting system. They suggested using a driver other than volume to allocate overhead. Brimson (1986) noted that most accounting systems did not provide the information necessary to manage automated manufacturing systems and Seed (1984) described changes needed in cost

Table 2.1
Models for Buyer-Supplier Cooperation Toward JIT

References	Findings
Goyal 1976	An order placement interval for the buyer to minimize joint variable costs per unit time
Kelle 1984	A minimum safety stock for a prescribed service level where the multiple delivery times are random and the demand is deterministic.
Banerjee 1986a	A joint economic order quantity between the buyer and supplier
Banerjee 1986b	A price at which the buyer purchases the supplier's EOQ
Goyal 1988	A modified version of a joint economic lot-size model that allows the producer to produce in lot sizes of nQ instead of lot-for lot bases.
Pan and Laio, 1989	Develop a single EOQ type model for a JIT delivery system
Ramasesh, 1990	Extend Pan and Laio (1989) by adding the shipping cost to the total relevant cost.
D'ouville, Willis, and Huston 1992	An optimal production rate and run length for the supplier to meet a JIT schedule
Kelle and Schneider 1992	Extend Kelle (1984) results to model the multi-stage production process. They approximate the minimum work-in-process inventory target level needed to provide a prescribed service level
Golhar and Sarker 1992	An optimal finished goods batch size for the supplier given raw material and the finished goods inventory costs, rate , and the shipment size
Goyal and Golpalakrishnan 1993	Optimal production rate and lot size for the supplier to meet a JIT schedule.
Natarajan and Goyal , 1994	Provide the legitimate reasons for holding a safety stock under JIT environment.
Aderohunmu, Mobolurin and Bryson 1995	Examine a JIT co-operative batching policy with an open exchange information between the buyer and the supplier
Banejrjee and Kim 1995	Integrated cooperation models that include the raw material supply in the manufacturer's and buyer's total cost.

Table 2.1 (Contd.)
Models for Buyer-Supplier Cooperation Toward JIT

Fazel 1997	A mathematical model has been developed to compare the annual cost of inventory for JIT and EOQ purchasing
Kim and Ha, 1998	Develop as integrated JIT lot-splitting model over a finite-planning horizon.
Miller and Kelle 1998	A JIT joint economic order quantity model has been presented that quantifies the compensation level in the negotiation process.
Pegell et al 1998	Validate the relationship between uncertainty, flexibility and safety stock in the context of JIT environment.
Kelle and Miller 1998	Incorporating a safety stock into deterministic JIT buyer-supplier models.

accounting systems in order to provide more reliable product cost information in advanced manufacturing environments.

Cooper and Kaplen (1988a) discuss the distortion of product costs by the traditional cost accounting systems used by several manufacturing firms (this paper is based on information gained from studying more than 20 firms). Mecimore and Bell (1995) describe the evolution of ABC from a product-costing focus to a process and business unit focus and eventually to a company-wide focus. Hardy and Hubbard (1992) contrasts traditional cost accounting with ABC, discussing the strengths and weaknesses of both systems, while Bonsack (1991) shows that standard costing and ABC are compatible.

Needy and Malzahn (1993) use simulation models to identify the conditions under which strategic decisions and resulting performance are differ for traditional cost accounting and ABC. Babad and Balachandran (1993) provide an optimization model that balances savings in information processing costs with loss of accuracy.

In recent years numerous case studies have been published describing the implementation and impact of ABC on organizations: Mays and Sweeny (1994), Mangan (1995) and Bharara and Lee (1996). Cooper (1991) describes a seven-step plan for implementing ABC systems and Sherman (1994) suggests a method to identify activities and drivers for ABC implementation. Except in the material management area, some authors have written articles describing ABC and its use in different areas of management. Pirrong (1993) describes the use of ABC in service industries. Lawson (1994) studies the use of ABC in hospitals. Roth and Sims (1991) apply ABC to warehousing and distribution; Lewis (1991) applies it to marketing.

2.5 Review of EDI Literature Related to JIT Partnership

One of the main tools that facilitate to work under the environment of JIT partnerships is Electronic Data Interchange (EDI). It can be defined as " the inter-organizational, computer-to-computer exchange of business documentation in standard, machine processable format (Emmelhainz, 1993). The research on EDI and JIT can be divided into two broad categories: 1) descriptive in nature where they address the importance of sharing information between a buyer and supplier utilizing EDI; 2) research based on management survey data, where they address the costs and benefits of implementing EDI. In this section, I review studies of both types.

Many researchers consistently recommend various aspects of communication for successful JIT partnerships (Coyle, Badri, and Langley, 1996, Carter and Ferrin, 1995). These include open and frequent sharing of information, sharing of sensitive and confidential information, and information concerning the supplier's production related issues. Others (Bowersox et al. 1989,La Londe and Cooper 1989) have

suggested that state of the art management information systems and information technology applications to JIT partnership functions are vital to a firm's success. More specifically, EDI has the potential to significantly enhance a firm's competitiveness.

Wang and Seidmann, (1995) state the benefits of EDI, which include: reductions in paperwork, personnel, inventory costs, and order lead-time. Anvari, (1992) concludes that, although the initial investment in such a system is large, the long-term cost savings and reduced planning complexities will ultimately offset the expense. Wang and Seidmann (1995) show that when the benefits the buyer experiences from the installation of EDI systems are high, it is in the buyer's interest to subsidize the supplier's adoption of an EDI system.

Newman (1988) argues that the sharing of information with suppliers should be the same, as it would be shared internally, because suppliers are regarded as an extension of the JIT manufacturer's operation. Discussions and sharing information in the areas of delivery schedule, usage of purchased parts, quality, design, production process, and production activities are essential for JIT working partnerships. In this way, suppliers are able to coordinate their production planning processes with JIT manufacturers. Mohr and Spekman, (1994) state that "By sharing information and being knowledgeable about each other's business, partners are able to act independently in maintaining the relationship over time". In fact, information sharing between buyers and suppliers is important to develop and maintain trust. Sharing this type of information requires trust between the firms. Mohr and Nevin, (1990) found if distrust or conflict is present; the open communication might convey

coercive power, which leads to a deleterious relationship. Empirical studies have shown that poor communication and feedback is one of the most important barriers in JIT working partnerships, and many JIT implementation problems can be overcome by improving communication between JIT suppliers and buyers (Celley et al., 1987; Lascelles and Dale, 1989).

2.6 Research Opportunities in the Existing Models

In general, most of the research relating to the buyer-supplier JIT partnership has been focused in two directions. The first direction is descriptive in nature, concerning with the perception of buyers and/or suppliers. The second direction of research has focused on quantifying the benefits and cost savings that would result in a partnership. Most of the models that quantify the benefits of buyer-supplier cooperation use the basic Economic Order Quantity (EOQ) relationship as a foundation for model building. [For example, (Goyal, 1976 and 1988), (Banerjee, 1986), (Joglekar, 1988),(D'ouville et al., 1992), (Golher and Sarker, 1992), (Goyal and Golpalakrishnann, 1993), (Banerjee and Kim, 1995), (Fazel, 1997), and (Miller and Kelle , 1998)].

All of the proposed models published in the literature have addressed two scenarios. The first scenario is where the order quantity (Q_B) is equal the production lot size (Q_S). More specifically, the number of shipments per order (n) equals the number of shipments per production lot size (m). In the second scenario, the shipment size (q_B) is equal the production lot size (Q_S). In other words, m=1. No one has addressed the case where the number of shipments per order buyer's order quantity is different from the number of shipments per supplier's production lot size,

hence m>1. This new extension is more realistic and it can provide more flexibility in choosing the appropriate lot size for the supplier. We expect that it can result in a overall cost savings.

Another shortcoming of the previously published models that quantify the buyer's and supplier's JIT partnership is the assumption of deterministic demand and lead times. There is always uncertainty in the customer's demand, but flexible resources and short production and supply lead times enable the required service level to be met in this case without holding safety stocks. In practice, however, the appropriate flexibility and capacity are not available or is too expensive. Therefore, either the buyer or the supplier has to hold safety stock to provide the appropriate customer service level. Only the case where the buyer is holding safety stock was examined (Kelle and Miller, 1998). All other models fail to consider an approximation for a safety stock that is necessary to ensure the required service level of supply. No research thus far provides a model for the case when the supplier is responsible for holding safety stock to provide the service level required by JIT partnership.

Another major problem associated with JIT models previously developed is the lack of cost data needed to quantify the costs and benefits of implementing JIT partnership. Several authors discuss the advantages of Activity Based Costing (ABC) over traditional accounting. The main issue that has been revealed from previous research is that ABC can satisfy the data requirement of the quantitative models. To the best of my knowledge, no research thus far examines the impact of ABC on JIT

models. In particular, no literature is available that would specify the cost activities, cost drivers and traceable costs of the buyer and supplier under JIT partnership.

Most of the previous models consider only the cost of manufacturing setup, inventory holding, and ordering, however, transaction costs especially ordering costs will change after establishing partnerships. The use of an EDI or internet connection can dramatically reduce the time and costs involved in placing orders and making payments. Therefore, once the partnership is functioning, the ordering costs for the buyer (other than shipping costs), would be close to zero. Inventory holding costs could be reduced because fewer inventory items will be in the system. Lower levels of inventory may also mean less scrap and rework, fewer inspections, less obsolescence, improved inventory control and management. This would result in more flexibility and quality improvement and other improvements. Therefore, from practitioner's point of view, realistic quantitative models should consider the synergies resulting from cooperative relationships under a JIT environment.

CHAPTER 3
MODEL FORMULATION AND SOLUTION

3.1 Introduction

JIT philosophy calls for small delivery quantities, which arrive on time, with the quantity and quality required. For JIT to be effective there should be a cooperative relationship between the buyer and the supplier. They should work together to enhance both their positions. There are few quantitative JIT models available in the literature. All of these models are based on economic order quantity type models, which are adjusted for multiple deliveries or consider the cooperation between the two parties. For example (Pan and Liao, 1989), (Ramasesh, 1990), (Golhar and Sarker, 1992), (Aderohunmu et al., 1995), (Banerjee and Kim, 1995), (Kim and Ha, 1998), and (Miller and Kelle, 1998).

The study extends the above results for different JIT scenarios. A new model is constructed considering a deterministic JIT environment (Model 2, described in Section 3.4.2) as an extension to Miller and Kelle (1998) model. We assume that the buyer's order quantity, Q_B, is delivered in n shipments of size $q = Q_B/n$. The supplier's production lot size can also be an integer multiple of the shipment size , $Q_S = mq$, and m can be different from n . Only the cases of m=1 and m = n were examined previously in the literature. We expect that this new extension can result in substantial cost savings by allowing more flexibility for the supplier to choose the appropriate production lot sizes. The proposed model determines the optimal values of the three decision variables, the shipment size ,q, the number of shipments of an order n, and number of shipments per production lot size ,m.

Under these assumptions, ideally, the buyer and supplier operate in a deterministic environment, so therefore, neither the buyer nor the supplier has to hold

safety stock. There is always uncertainty in the customer's demand, but flexible resources and short production and supply lead times enable the required service level to be met in the case of perfect JIT supply without holding safety stock. Usually in practice, however, the appropriate flexibility and capacity are not available or are too expensive to maintain. We call this stage the time of transition to JIT supply where safety stock must be held to provide the appropriate service level.

We extend the deterministic JIT approach by incorporating into the model the safety stock expression in Kelle (1984) and Kelle and Schneider (1992) into the joint total relevant cost and thus derive the optimal order quantity and number of shipments under different scenarios. The study considers the situation when the supplier is not reliable, or is unable to provide small, frequent deliveries on time with established quantity or quality levels. The study incorporates the safety stock into the model under the situation of "not quite JIT" where the buyer and supplier are in transition to JIT supply and either the buyer or the supplier holds a safety stock. Only the case where the buyer is holding safety stock was examined previously by (Kelle and Miller, 1998). We provide a new case where the supplier is holding safety-stock under transition to JIT (Model 4, described in Section 3.4.3). In the spirit of JIT, the study finds the minimum safety stock needed in order to protect against shortages that may be caused by delivery delays. The safety stock that is required to provide the appropriate customer service level depends on the number of shipments and the shipment size. The proposed models jointly determine the optimal values of the four decision variables: the order quantity, the shipment size, the number of shipments and the safety stock.

In Section 2, first, we addresses the optimal ordering and shipment policy of the buyer and the cost savings achieved by receiving JIT supply. Then, we apply the results of Miller and Kelle (1998) for the case when the buyer has to hold some safety stock to ensure an appropriate service level for its customers. In Section 3, we deal with the optimal production policy of the supplier and quantify the supplier's advantages and costs of a JIT delivery requirement promised by the supplier to the buyer. Next, we examine the effect of decreasing uncertainty on the cost of the supplier through focusing on the production related costs. Finally, we provide a new model for the case when the supplier holds safety stock to ensure timely delivery to the buyer according to the JIT supply contract. Section 4, provides the joint optimal ordering, production, and shipping policy that minimizes the total relevant costs of the two parties involved. The four models presented here consider four different scenarios.

3.2 Quantifying the Costs and Benefits of the Buyer Adopting JIT Supply

Two models are presented in this section each representing a different approach to quantifying the costs and benefits of the buyer adopting JIT supply. The first one uses the deterministic approach as a foundation for model building. The second model incorporates safety stock held by the buyer.

3.2.1 Deterministic Model for the Buyer's Optimal JIT Policy

The buyer's major quantifiable benefit from JIT delivery is the low inventory level that results in savings in inventory holding cost and increased flexibility as a result of receiving small-lot shipments. Additional benefits include less spoilage, less obsolescence, and other factors that are difficult to quantify, but can be considered as a part of the holding cost factor. On the other hand, the buyer may realize an increase in

receiving cost of shipments due to more frequent deliveries. This includes all the costs that are associated with small lot shipment such as (a) freight, (b) sampling/quality control, and (c) receiving, handling and storage under the umbrella of receiving costs. Also, a loss of discount rates may be incurred.

Our goal is to quantify the above savings and extra costs for the buyer. First, we extend the traditional economic order quantity model (EOQ) for JIT systems that consider a known, constant demand rate for a product. The total relevant cost for the buyer is expressed as the total cost of ordering and holding inventory as given by Banerjee (1986a). The difference is that this model is adjusted for multiple deliveries of an order, which is typical for JIT, a shipping cost has been added as in Ramasash (1990). Also, we add a new cost parameter that will consider the managerial concern of having an ordering quantity, which is too large. The new cost parameter will be discussed later in this section.

The following assumptions and notation for the buyer are proposed:

B1). The demand for the product is known and

D: denotes the expected annual demand of the product considered.

B2). The buyer can decide the following two quantities:

the order size Q_B, (or contract quantity), that is delivered in small shipments, and

n: the number of shipments of an order during a contract period.

To simplify the quantitative analysis, we assume that the delivery quantities are the same size, $q = Q_B/n$.

B3). The following cost factors are used in the quantitative model:

$C_{B:}$ purchasing cost of a unit of the considered product for the buyer,

A_B: total fixed cost of a purchase order,

r_B: inventory holding cost factor, the proportion of dollar value of the stock of the buyer,

Z_B: receiving cost per shipment for the buyer.

With the above notation, the annual **ordering cost** for the buyer can be expressed in the usual way by

$$CO_B = A_B (D/Q_B) \tag{1}$$

The annual **receiving cost** for the buyer is

$$CR_B = Z_B (D/Q_B). \tag{2}$$

This cost consideration makes traditional large orders and shipments economical, but it may result in very large holding costs. The inventory **holding cost of the cycle stock** can be expressed by

$$CH_B = r_B C_B (Q_B/2). \tag{3}$$

Therefore, the **total relevant cost** for the buyer is

$$TRC_B(Q_B) = A_B (D/Q_B) + Z_B (D/Q_B) + r_B C_B (Q_B/2) \tag{4}$$

This model considers only a single delivery for each order. Implementing JIT, which involves n deliveries of an order, the total inventory cost is

$$TRC_B (Q_B,n) = A_B (D/Q_B) + r_B C_B (Q_B/2n) + Z_B (nD/Q_B) \tag{5}$$

There is a significant reduction in inventory holding cost, which results from implementing JIT. The **cost saving in inventory holding** can be expressed as

$$\Delta CH_B(\text{inventory}) = [r_B C_B (Q_B/2)] - [r_B C_B (Q_B/2n)] = r_B C_B Q_B (n-1)/(2n) \tag{6}$$

Assuming that the buyer will pay at least a part of the shipping and receiving cost, the buyer will recognize a significant increase in this cost due to multiple deliveries. The **cost increase in receiving and shipment** can be expressed as

$$\Delta CR_B = [Z_B\,(nD/Q_B)] - [Z_B\,(D/Q_B)] = Z_B\,D\,(n-1)/Q_B \tag{7}$$

The total relevant cost of the buyer expressed in (5) can be rewritten in the form:

$$TRC_B(Q_B,n) = \frac{X(n)}{Q_B} + Q_B Y(n) \tag{8}$$

with notation

$$X(n) = D\ (A_B + Z_B n) \tag{9}$$

$$Y(n) = \frac{r_B C_B}{2n} \tag{10}$$

For a given n, the optimal value of Q_B can be expressed, by taking the derivative of the cost function (8) with respect to Q_B, and setting it equal to zero, yielding the following expression

$$Q_B^{\bullet}(n) = \sqrt{\frac{X(n)}{Y(n)}} = \sqrt{\frac{2nD(A_B + Z_B n)}{r_B C_B}} \tag{11}$$

To find the optimal n, we can substitute $Q_B(n)$ in the cost function (8), providing the buyer's annual relevant cost as a function of n.

$$TRCB(n) = 2\sqrt{(X(n)Y(N))} = 2\sqrt{\frac{D(A_B + Z_B n) r_B C_B}{2n}} \tag{12}$$

This is equivalent to finding the n, which minimizes

$$[TRC_B\,(n)]^2 = \frac{2DA_B r_B C_B}{n} + 2DZ_B r_B C_B \tag{13}$$

Ignoring the terms which are independent of n, one can reduce the minimization problem to that of minimizing

$$\frac{2DA_B r_B(C_B + L_B}{n} \tag{14}$$

From the expression above, it can be seen that the optimal n for the buyer is infinity. It shows that Q_B also approaches infinity as n goes to infinity. This result is not surprising, since the cost model (5) results in a lower cost as the order quantity, Q_B, increases and the shipment quantity, $q=Q_B/n$, remains unchanged. The annual ordering cost is decreased, but the receiving and inventory holding cost are unchanged. This result has not yet been published in the quantitative literature, however, it supports the tendency in practice, of having very long purchase order contracts in JIT supply agreements to save on ordering costs without increasing the holding costs. The cost improvement is marginally decreasing as the order quantity increases. For the order quantity, there is a reasonable, managerial limit where the loss of flexibility, and concerns of product changes and long commitments outweigh the annual ordering cost decrease. Therefore, we introduce a new cost parameter that will consider the managerial concern of having an order quantity Q_B which is too large. We assume that the part of the order quantity that is not delivered to the buyers is a commitment that must be bought in the future. This commitment results in a loss of flexibility for changes in the order quantity. Although, it is a small disadvantage compared to the saving in inventory holding cost, still, it is important if very long commitments are considered. For the sake of simplicity, a linear approximation for the pattern of L_B has been used in the model. We propose the following new cost parameter:

B4). L_B : additional cost of losing flexibility per unit ordered but not delivered.

The annual **additional cost of losing flexibility** is

$$CL_B = L_B C_B (Q_B/2) \tag{15}$$

Since the rate of $Q_B/n = q$ is the shipment size, we can deal with the optimal shipment size. The new total relevant cost of the buyer, including L_B, can be

$$TRC(q,n) = \frac{D}{nq}A_B + \frac{r_B C_B q}{2} + \frac{D}{q}Z_B + \frac{L_B C_B nq}{2} \tag{16}$$

expressed as a function of the shipment size q

It can be expressed, similar to (8), in the form

$$TRC(q,n) = \frac{x(n)}{q} + q\,y(n) \tag{17}$$

With notation

$$x(n) = D\left(\frac{A_B}{n} + Z_B\right) \tag{18}$$

$$y(n) = \frac{r_B C_B + L_B C_B n}{2} \tag{19}$$

Similar to (11), for a given n, the optimal value of the shipment size, q, can be expressed as

$$q_B^*(n) = \sqrt{\frac{x(n)}{y(n)}} = \sqrt{\frac{2D\left(\frac{A_B}{n} + Z_B\right)}{r_B C_B + L_B C_B n}} \tag{20}$$

This value is well defined for any n value and as n gets extremely large, the term A_B/n diminishes and the shipping cost, Z_B, will act as an ordering cost in the traditional economic order quantity.

Substituting q (n) in the cost function (18) provides the minimal joint total cost as a function of n

$$TRC_B(n)=2\sqrt{x_B(N)\,y_B(n))} \qquad (21)$$

Relaxing the integer requirement on n, we can find the optimal n by minimizing

$$\min \quad x_B(n), y_B(n)=\frac{DA_B}{n}\left(\frac{r_BC_B+L_BC_Bn}{2}\right)DZ_B\left(\frac{r_BC_B+L_BC_Bn}{2}\right) \qquad (22)$$

which yield

$$=\frac{U}{n}+nV+Const. \qquad (23)$$

with notation

$$U=\frac{DA_Br_BC_B}{2} \qquad (24)$$

and

$$V=\frac{DZ_BL_BC_B}{2} \qquad (25)$$

Thus, the optimal number of deliveries can be found by taking the derivative of (23), setting it equal to 0, and expressing n as

$$n^*=\sqrt{U/V}=\sqrt{\frac{A_Br_B}{Z_BL_B}} \qquad (26)$$

This n* is generally not integer. Substituting the two integer values surrounding n* into the cost function (5), we can get the best integer value of n that provides the overall (global) optimal integer because of the convexity of the cost function.

3.2.2 Incorporating Safety Stock at the Buyer

We incorporate safety stock into the model under three situations. First, in a traditional buyer supplier relationship (no JIT), the buyer holds finished goods safety stock to provide an appropriate customer service level considering the demand uncertainty and possible shipment delays. In the second case, when the buyer and supplier move toward JIT purchasing, we assume that the vendor tries JIT deliveries but

capacity, scheduling, transportation or quality problems may occur. These problems can cause material supply shortages and a small amount of material safety stock is needed to protect against possible delays. Third, we present the case where the buyer and supplier are operating in JIT agreement. The supplier is responsible for timely shipments and the supplier has to hold safety stock to ensure the appropriate delivery under any circumstances.

3.2.2.1 Safety Stock in Traditional System (no JIT)

As a result of the demand uncertainty and possible shipment delays, the buyer holds a safety stock to provide an appropriate customer service. We introduce the following notation for the quantitative models of safety stocks, in addition to the notation of Section 3.2.1:

α: the required service level, the probability of no stockout

S_B: the quantity of safety stock held at the buyer

K: safety factor that depends on the customer service level, α

L: known constant lead-time of the supply to the buyer

σ_D: standard deviation of daily demand

r: inventory level at which an order is placed (reorder point)

d_{LD} : random variable representing demand during lead-time

μ_{LD}: average demand during the lead-time

σ_{LD}: standard deviation of the demand during the lead-time

The reorder point is

$$r = \mu_{LD} + S_B \tag{27}$$

We use the common approximation that the demand during the lead-time is normally distributed with expected value of μ_{LD} and standard deviation σ_{LD}. Hence, the service level α, the probability of no shortage is

$$P(r \geq d_{LD} = \phi\left(\frac{r-\mu_{LD}}{\sigma_{LD}}\right) = \alpha \quad (28)$$

which yields

$$r = K\sigma_{LD} + \mu_{LD} = S_B + \mu_{DL} \quad (29)$$

with notation

$$\phi^{-1}(\alpha) = K \quad (30)$$

Where ϕ denotes the cumulative distribution function of the standard normal distribution, and ϕ^{-1} denotes its inverse.

For independent daily demand

$$\sigma_{LD} = \sigma_D \sqrt{L} \quad (31)$$

Which is a common approximation for the standard deviation of lead-time demand. Based on the above expression, we approximate the safety stock as

$$S_B = K\sigma_{LD} \quad (32)$$

A common safety stock approximation can be used for the case of random lead-time by incorporating the following additional two parameters

μ_L: average lead-time from the supplier to the buyer,

σ_L: standard deviation of the lead-time,

d_r: average daily demand.

The necessary safety stock which provides a service level α can be approximated, assuming independent demand in the subsequent periods of the lead-time, by

$$SB = K\sqrt{\left(\mu_L \sigma_D^2 + d_r^2 \sigma_L^2\right)} \tag{33}$$

In several practical cases, there is an autocorrelated demand that requires the autocorrelation coefficients to be included into the model. Estimating the autocorrelation coefficients, and handling the more complex expression makes the model analytically intractable and so it is not used in most applications.

Under a JIT environment, both the average lead time and the variability of the lead time can be reduced considerably using frequent small shipments. Denoting the safety stock under JIT by S_{JIT}, the **cost saving in holding safety stock** can be expressed as

$$\Delta CH_B(\text{safety stock}) = [r_B\, C_B\, (S_B)] - [r_B\, C_b\, (S_{JIT})] = r_B\, C_B(S_B - S_{JIT}) \tag{34}$$

3.2.2.2 Safety Stock under the Transition to JIT

The ultimate goal of the buyer in JIT is that the supply arrives in small, frequent deliveries, on time, according to the request of the buyer. However, many times the supplier is unable to deliver frequent shipments on time as a result of capacity, transportation problems, machine breakdowns, or production scheduling problems that cannot be solved at that time. This situation can be called imperfect coordination, which is typical during the transition to JIT.

Kelle and Miller (1998) presented an approximation for the minimum safety stock required providing the necessary service level under the situation of having random delays in shipments. This approximation will be incorporated into our inventory models.

The safety stock, required to provide the necessary service level, depends on the shipment frequency, among other things. Thus the consideration of a safety stock changes the optimal shipment policy. In the spirit of JIT, we find the minimum safety stock, combined with the best shipment frequency for the buyer.

In order to derive the approximation for the required safety stock, in addition to the assumptions B1) to B3) used in section 3.2.1 and 3.2.2.1, we introduce the following assumptions and notation:

B4). The demand has a known average rate, d_r. First, we assume that the demand follows a uniform pattern. We extend this assumption later to the case where the demand rate is changing according to the customer's request which is unknown at the time of safety stock planning.

B5). The order quantity, Q_B, is delivered in n shipments of equal size, $q = Q_B/n$ in the time interval of the order contract, denoted by (0,T), where $T = Q_B/d_r$.

B6). The shipment times are independent identically distributed (i.i.d.) random variables in (0, T), arranged in ascending order $t_1 < t_2 < \ldots < t_n$. First we assume that the shipment times are uniform random variables in (0, T). We extend this assumption later to general i.i.d. random variables. The critical assumption is that the supplier tries to follow the pattern of the demand according to the JIT supply agreement, but because of production, capacity, or transportation problems there are random disturbances in the shipment times.

Based on the above assumptions, we present the following model described in Kelle and Miller (1998) to approximate the situation. Their approximate for safety stock

will be included in our cost model. First, for known demand rate , d_r, the cumulative demand in the period (0,t) can be described as

$$F(t)= d_r t \qquad \text{for} \quad 0 \le t \le T \tag{35}$$

The cumulative delivery in period (0,t), is an increasing step function, $G_n(t)$, with the step size of the shipments $q = Q_B/n$, at n uniformly distributed random delivery times $t_1 \le t_2 \le .. \le t_n$ in (0, T). $G_n(t)$ is given by the following expression:

$$G_n(t) = \begin{cases} 0 & \text{if } 0 \le t \le t_1 \\ kq & \text{if } t_k < t_{k+1}, \quad k = 1,2,\ldots,n-1 \\ nq = Q_B & \text{if } t_n < t \le T \end{cases} \tag{36}$$

$G_n(t)$ will approach the uniform pattern of F(t) according to the JIT coordination between the supplier and the buyer. The required service level, α, is the probability of no stockout in an order period, and S_B denotes the safety stock that is to be planned at the ordering to provide the required service level.

For any $t \le T$, there is no shortage in the time interval (0,t), if the safety stock plus cumulative amount delivered in period (0,t) is larger than or equal to the cumulative amount of demand in period (0,t). This inequality must hold in each point of the period $[0 \le t \le T]$ to insure a continuous supply. With the above assumptions and notation, the no shortage requirement is

$$S_B + G_n(t) \ge F(t) \qquad \text{for each} \quad 0 \le t \le T \tag{37}$$

So, the service level, the probability of no shortage, can be expressed as

$$P(S_B) = \text{Prob}\,[S_B + G_n(t) \ge F(t) \quad \text{for } 0 \le t \le T] \tag{38}$$

Considering that $T = Q_B / d_r$, F(t) can be normalized

$$F(t) = d_r t = Q_B\, t/T = Q_B\, F^*(u) \text{ with } u = t/T \tag{39}$$

where $F^*(u) = u$ in (0,1), $F^*(u) = 0$ for $u \le 0$, and $F^*(u) = 1$ for $u \ge 1$. Thus $F^*(u)$ has the same properties as the distribution function of a random variable U, where U is a uniformly distributed on (0,1).

Since $q = Q_B/n$, $G_n(T)$ can be normalized, similarly as with F(t), in the following form

$$G_n(t) = Q_B G^*_n(u) \quad \text{with} \quad u = t/T \tag{40}$$

Where

$$G^*_n(u) = \begin{cases} 0 & \text{if} \quad 0 \le u < t_1/T = u^*_1, \\ k/n & \text{if} \quad t_k/T = u^*_k < u \le u^*_{k+1} = t_{k+1}/T,\ k = 1,2,\ldots,n-1 \\ 1 & \text{if} \quad t_n/T = u^*_n < u \le 1 \end{cases} \tag{41}$$

and $u^*_1 < u^*_2 < \ldots. < u^*_n$ can be considered as a random, ordered sample of a uniform distribution on (0,1). Thus $G^*_n(u)$ has the same properties as an empirical distribution function of U, where U is a uniformly distributed on (0,1).

Substituting $S_B = Q_B M_B$ in (38) , we have the equivalent service level expression

$$P\,(Q_B M_B) = \text{Prob}\,[Q_B M_B + Q_B\, G_n^*(t/T) \ge Q_B F^*(t/T), \quad \text{for } 0 \le t \le T] \tag{42}$$

Using the notation $u = t/T$

$$P_\alpha\,(M_B) = \text{Prob}\,(M_B + G^*_n(u) \ge F^*(u), \quad \text{for } 0 \le u \le 1) \tag{43}$$

Finding the safety stock, $S_B = Q_B M_B$, that provides the required service level, α, we must solve the following equation for M_B

$$P_\alpha\,(M_B) = \alpha \tag{44}$$

In expression (34), we have a cumulative distribution function, $F^*(u)$, and an empirical distribution function, $G^*_n(u)$, of the same uniform random variable U on (0,1). The exact distribution, $P_\alpha\,(M_B)$, is expressed by Birnbaum and Tingey (1951).

$$P_\alpha(M) = \alpha = 1 - \sum_{nM \le j \le n}^{n} \frac{nM_B}{n + nM_B - j} \binom{n}{j} \left(\frac{j}{n} - M_B \right)^j \left(1 + M_B - \frac{j}{n} \right)^{n-j} \tag{45}$$

Equation (44) can be solved numerically for M using expression (45), but it is a tedious procedure for practical application and numerical analysis. Therefore, we want to provide a simple approximate expression for P_α (M_B). Based on asymptotic theory of empirical distribution functions (Wilks, 1967):

Prob $\{\sqrt{n}[F^*(u) - G^*_n(u)] \le y$, for all $0 \le u \le 1\} \rightarrow 1\text{-}\exp\{-2y^2\}$, as $n \rightarrow \infty$ (46)

The above probability is equivalent to

Prob $\{F(t) - G_n(t)] \le y/\sqrt{n}$, for all $0 \le t \le T\}$ (47)

and it is also equivalent to

Prob $\{Q_B F(t) - Q_B G_n(t)] \le yQ_B/\sqrt{n}$, for all $0 \le t \le T\}$ (48)

Using the notation $M_B = yQ_B/\sqrt{n}$, we have $y = M_B \sqrt{n}/Q_B$ that can be substituted in (48) to get the asymptotic relation

$P_\alpha (M_B) \rightarrow 1\text{-}\exp[-2\, M_B\, n\, /Q_B^2 \quad]$ as $n \rightarrow \infty$ (49)

For large n values, we can consider the asymptotic expression (49) as an approximation

$P_\alpha (M_B) \approx 1\text{-}\exp[-2n\, (M_B{}^2/Q_B^2)]$ (50)

From the service level requirement of expression (44) using the above approximation, we get the following simple approximation for safety stock

$$S_B = QB\sqrt{\frac{\ln\left(\frac{1}{1\text{-}\alpha}\right)}{2n}} \tag{51}$$

Expression (51) will be included in formulating the cost function of the buyer in Model 3 where described in Section 4.3.3. The above results are derived under the assumption that $F^*(u)$ is the distribution function and $G_n^*(u)$ is the empirical distribution function of the uniform random variable, U. Since expression (46) and asymptotic relation (47) are based on order statistics $u^*_1 < u^*_2 < \ldots < u^*_n$ (distribution-free statistics) the above results are valid for any random variable (Wilks, 1962), not only the uniformly distributed U. The only requirement is that $F^*(u)$ is the cumulative distribution function and $G_n^*(u)$ is the empirical distribution function of the same random variable, U. That means $F^*(u)$ can be any nondecreasing function in $0 \leq u \leq 1$, with the property of $F^*(0) = 0$ and $F^*(1)=1$. The pattern of $F^*(u)$ defines a random variable U. As long as the random shipment times follow the same pattern, the empirical distribution function, $G_n^*(u)$ can be assumed to belong to the same random variable, U, and the above statements are valid.

In the case of a JIT agreement, we can assume that the pattern of the delivery follows the pattern of demand: in high-demand periods more frequent deliveries are requested, in low-demand periods the buyer requests less frequent deliveries. The supplier tries to deliver according to the buyer's request. Thus, we can consider the cumulative demand as the cumulative distribution function and the cumulative delivery as the empirical distribution function of the same random variable, U. Since we don't need to specify the distribution of U, that means, no specific information of the pattern of the variable demand is required. Thus, as an extension of the model, we can assume that the demand pattern is not uniform and can even be unknown at the time of safety stock planning. This is the main advantage of the model because, in practice, typically we do

not know the demand pattern ahead of time, still as long as coordination exists between the buyer and supplier, the assumptions are realistic. This is the case for JIT supply.

The expression (51) shows that the required safety stock will increase as the order size, Q_B, and service level, α, are increasing. In addition, the required safety stock is decreasing with an increase in the number of shipments, n. This relation shows the advantage of JIT. The asymptotic approximation in (50) and (51) can be very inaccurate for small n. The error of approximations and there correction will be discussed in details in the next chapter. We provide a new correction factor where is based on regression analysis (described in Section 4.3.2.1)

3.3 Quantifying the Costs and Benefits of Adopting JIT by the Suppliers

Several studies show that one of the major motivators for the suppliers to implement JIT partnerships is to secure a reliable market. Long-term contracts guarantee business as long as the supplier meets the delivery terms. Also, long-term contracts provide greater demand certainty, larger market share, and an incentive to invest in product /cost improvement programs over a longer term. Providing a JIT supply means additional costs for the vendor. The major sources of cost increase are the increased setup cost, additional inventory holding costs and transportation cost due to the buyer's frequent delivery policy.

First, we examine the effect of decreasing demand uncertainty on the cost of the producer through focusing on the production related costs. We introduce a new model that quantifies the advantages and the costs of maintaining flexible resources. In the next part, we examine additional inventory-related costs of the supplier. The last section will discuss our new model for the supplier's safety stock, which incorporated into the

supplier cost model. The previous quantitative models have been failed to deal with supplier safety stock under JIT delivery requirement.

3.3.1 Reduction in Production Costs

The relative demand certainty allows the supplier to dedicate a portion of the firm's resources to meet this demand. By doing so, the supplier will benefit by having fewer slack resources. This security for the supplier justifies investments that result in reduction of the production and setup cost. First, we examine the effect of decreasing demand uncertainty on the cost of the producer through focusing on the production related costs. To quantify the reduction in production cost, we have the following assumptions and notations concerning the supplier.

S1). The annual demand consists of two parts:

D_C = the fixed contracted annual demand, and

D_R= random part of the annual demand, normally distributed with expected value μ and standard deviation σ.

S2). The vendor has dedicated and fixed production resources denoted by

R_d = annual production capacity of dedicated production resources,

R_f = annual production capacity of flexible production resources.

S3). We have the notation

P = the annual production quantity (the actual annual volume sold),

We assume that the random part of the annual demand is normally distributed. Thus, the total annual production quantity, P, is also normally distributed with expected value,

$E(P)=D_C + \mu$, and standard deviation, σ. We assume that the dedicated resource is set at the level of expected production, $E(P)$.

S4). The following cost factors are considered,

v_d = unit production cost with dedicated resources,

v_f = unit production cost with flexible resources,

u = unit cost of unused dedicated production resources.

We assume that the unit cost with dedicated resources is less than with flexible ones. If the dedicated resources are not used they have extra costs, while unused flexible resources can be utilized in other production areas without major additional costs.

Our goal is to express

C_P = the expected total unit cost of production, including unused production resource cost.

If the annual production quantity is larger than the amount of dedicated resources ($P \geq R_d$), the total cost of producing P units a year is

$$v(P) = v_d R_d + v_f (P - R_d) \tag{52}$$

If the annual production quantity is larger than the amount of dedicated resources ($P < R_d$), the total production and unused capacity cost is

$$v(P) = v_d P + u (R_d - P) \tag{53}$$

We can express the expected unit production cost, C_P, by integrating the unit production cost function, $v(P)/P$, according to the normal density function (with expected value, $E(P)$, and standard deviation, σ).

$$C_P = \int_0^{\infty} \frac{v(P)}{P} \varphi\left(\frac{P - E(P)}{\sigma}\right) dp \tag{54}$$

Where φ denotes the standardized normal density function.

Based on the above simple model, we can express the decrease in the unit cost of production depending on the decrease of demand uncertainty. In other words, we can express the savings that can be achieved by decreasing the demand uncertainty through buyer-supplier cooperation. This is one part of the additional wealth generated by the cooperation between supplier and buyer. A numerical investigation will be presented and the results will be discussed in the next chapter.

3.3.2 Inventory Related Costs

When the supplier is implementing JIT, additional inventory costs are incurred. In this section, we examine the additional inventory-related costs of the supplier. These are the increase in set-up cost, additional inventory holding cost, and increased shipment cost. First, we extend the traditional economic order quantity model (EOQ) for JIT systems that consider a known, constant demand rate for a product. The total relevant cost for the supplier is expressed as the total cost of setup and inventory holding costs as given by Banerjee (1986a). The difference is that this model is adjusted for multiple deliveries of an order, which is typical for JIT, the supplier's holding cost is also altered, as given by Golhar and Sarker (1992), for a JIT supply system, and a shipping cost has been added as in Ramasash (1990).

To quantify these costs, we introduce the following additional assumptions and notation for the supplier

S5). We assume that the supplier is producing the item with

p_r = production rate expressed on daily basis and

Q_S = production lot size,

q = shipment size required

m= the number of shipments per lot, where (Q_S = mq)

S6). The supplier has the following cost factors

A_S = setup cost for the supplier (producer),

r_s = inventory holding cost factor ($/$/year),

C_S = variable cost of the finished product for the supplier,

Z_S = supplier's costs related to each shipment to customer.

The annual shipment cost is directly proportional to the annual number of shipments, D/q

$$Z_S\,(D/q) \tag{55}$$

The annual setup cost can be expressed as

$$A_s\,(D/Q_S) \tag{56}$$

First, we consider the case where the supplier's lot size, Q_S, is equal to the required shipment size, q (the case of m =1). In this case, the total inventory for the supplier is calculated in a different way from the buyer. Once the supplier has shipped the lot to the buyer the inventory for the supplier becomes zero until the start of the next production run. The average inventory will still be $Q_S/2$, but the supplier will hold that inventory for only a fraction, (d_r/p_r), of the year. Therefore, the total inventory holding cost for the supplier is

$$\frac{d_r Q_s}{2 p_r} r_s C_s \tag{57}$$

So the total relevant cost with a single delivery for each order is:

$$TRC_s = A_s \frac{D}{Q_s} + r_s C_s \frac{Q_s d_r}{2p_r} + Z_s \frac{D}{Q_s} \tag{58}$$

This model considers only a single delivery for each order. The annual setup cost can be reduced, if the lot sizes are larger than the shipment sizes. In this case, however, additional inventory holding cost applies to the finished goods that are not shipped instantly. Consider the case when a large lot size is more economic and it is chosen as an integer multiple of the shipment size

$$Q_S = mq \tag{59}$$

which means the annual number of setups is m times less than the annual number of shipments.

During the implementation of JIT, which involves multiple deliveries of the orders, the inventory holding cost of the cycle stock can be expressed by using the expression published in Joglekar (1988) as

$$r_s C_s \frac{Q_s}{2}(1 - \frac{d_r}{p_r} - \frac{1}{m} + \frac{2d_r}{mp_r}) \tag{60}$$

The total relevant inventory cost for the supplier is

$$TRC_s(Q_s, m) = A_s \frac{D}{Q_s} + r_s C_s \frac{Q_s}{2}\left[1 - \frac{d_r}{p_r} - \frac{1}{m} + \frac{2d_r}{mp_r}\right] + Z_s \frac{Dm}{Q_s} \tag{61}$$

It can be expressed in the following form (similar to costs expressed in (6))

$$TRC_s(Q_s,m) = \frac{X(m)}{Qs} + Y(m)Q_s \tag{62}$$

With notation:

$$X(m)=D\left(\frac{A_s}{m}+Z_s\right) \tag{63}$$

$$Y(m)=\frac{r_s C_s}{2p_r}\left[m(p_r-d_r)+2d_r-p_r\right] \tag{64}$$

For a given m, we can express the optimal value of Q_S, by taking the derivative of the cost function (61) with respect to Q_S, and setting it equal to 0, as

$$Q_S^*(m)=\sqrt{\frac{X(m)}{Y(m)}}=\sqrt{\frac{2Dp_r\left(\frac{A_S}{m}+Z_S\right)}{r_S C_S(m-md_r-1+2d_r)}} \tag{65}$$

To find the optimal m, we can substitute $Q^*_S(m)$ in the cost function that provides the buyer's annual relevant cost as a function of m, where m is an integer

$$TRC_S(m)=2\sqrt{(X(m)Y(m))}$$

$$=2\sqrt{2Dr_S C_S\left(\frac{A_S}{m}+Z_S\right)\left[\frac{m(p_r-d_r)+2d_r-p_r}{p_r}\right]} \tag{66}$$

If we relax the integer requirement on m, we can approximate the optimal m for the supplier by finding the m which minimizes the $TRC_S(m)$. This is equivalent to finding the m, which minimizes

$$(TRC_S)^2=Min\frac{U}{m}+Vm+Cont.$$

where

$$V=\frac{2Dr_S Z_S(p_r-d_r)}{p_r} \quad and \quad U=\frac{2Dr_S C_S A_S(2d_r-p_r)}{p_r} \tag{67}$$

Thus, the optimal number of deliveries can be found by taking the derivative of (67), setting it equal to 0, and expressing m as

$$m = \sqrt{\frac{U}{V}} = \sqrt{\frac{A_S(2d_r - p_r)}{Z_S(p_r - d_r)}} \tag{68}$$

Substituting the two integer values surrounding m back into the total cost expression (66), we can find the optimal integer m that provides the overall minimum cost because of the convexity of the cost function. For $2d_r < p_r$ the equation (68) has no real solution. Considering that the cost function is a decreasing function of m in this case, we can conclude from that the optimum is

$$m = 1 \qquad \text{if} \quad 2d_r < p_r. \qquad \text{for } Z_S > 0 \tag{69}$$

For this case, the optimal production lot size is

$$Q_s^* = \sqrt{\frac{2Dp_r(A_s + Z_s}{r_sC_s(d_r/p_r)}} \tag{70}$$

and the optimal total relevant cost is

$$TRC_s^* = \sqrt{2Dp_r(A_s + Z_s)rC_sd_r/p_r} \tag{71}$$

if $2d_r < p_r$.

Similarly, we can find the optimal m, for the case of $Z_S = 0$, by minimizing

$$\frac{DA_sC_sr}{2}\left[1 - \frac{d_r}{p_r} - \frac{1}{m} + \frac{2d_r}{mp_r}\right] \tag{72}$$

That is equivalent to minimizing

$$\frac{2d_r - p_r}{m} \tag{73}$$

It provides a similar result as in the case where $Z_S > 0$, that the optimal

$$m = 1 \qquad \text{for } 2d_r < p_r \tag{74}$$

However,

$$m \to \infty \qquad \text{for } 2d_r > p_r \text{ .(75)}$$

3.3.3 Incorporating Safety Stock at the Supplier

Here we consider the situation, when the supplier relies on keeping a safety stock of finished goods on hand to meet the buyer's shipment request, on time, according to the JIT delivery agreement. No quantitative models have been published yet dealing with the supplier safety stock under JIT delivery requirement. This is typical in the transition state to JIT, that the supplier can have capacity, flexibility, quality, or scheduling problems preventing the on time delivery. In addition to the same assumptions used in section 3.2.2.2, we have the following additional assumptions and notation:

S7). The shipment size $q = Q_B/n$ and the production lot size $Q_S = mq$ ($k = n/m$). The cumulative amount, $H_k(t)$, produced in the interval $(0,t)$, is a non-decreasing function of t for ($0 \leq t \leq T$). The setup times are independent identically distributed (i.i.d.) random variables arranged in ascending order $s_1 < s_2 < \ldots < s_k$. The cumulative production, $H_k(t)$, can be expressed as a step function:

$$H_k(t) = \begin{cases} 0 & \text{if } 0 \leq t \leq s_1 \\ imq & \text{if } s_i < t \leq s_{i+1}, i = 1,2,,\ldots,k-1 \\ kmq = Q_B & \text{if } s_k < t \leq T \end{cases} \tag{76}$$

S8). The random setup times follow the same distribution, U, as the delivery requirements of the supplier.

As in the buyer's model earlier, we assume that the cumulative delivery requirement to the buyer is an increasing step function, $G_n(t)$, described according to (29). We assume that $G_n(t)$ and $H_k(t)$ have the same pattern, since the pattern of the supplier's

production will approach the pattern of the delivery requirements of the buyer according to the JIT coordination between the supplier and the buyer.

The required service level α is the probability of no stockout in an order period, and S_S denotes the safety stock that is to be planned at the beginning of the contract to provide the required service level for the buyer.

There is no shortage in (0,T), if the safety stock at the supplier plus the cumulative amount produced in period (0,t) is larger than or equal to the cumulative amount of supplies required by the supplier up to time t to the buyer. This inequality must hold for each t in the period (0, T) to insure a continuous supply.

With the above assumptions and notation, there is no shortage in the buyer's supply if

$$S_S + H_k(t) \geq G_n(t) \quad \text{for each} \quad 0 \leq t \leq T \tag{77}$$

So, the probability that the supplier does not have a shortage in the contract period (0,T) is

$$P_\alpha (S_S) = \text{Prob}\ [S_S + H_k(t) \geq G_n(t) \ \ \text{for}\ \ 0 \leq t \leq T] \tag{78}$$

Substituting $S_S = Q_B M_S$ we have

$$P_\alpha (Q_B M_S) = \text{Prob}\ (Q_B H_k(t/T) \leq Q_B M_S + Q_B G_n(t/T) \quad \text{for}\ 0 \leq t \leq T) \tag{79}$$

Similarly to the procedure followed in normalizing $G^*_n(t)$ for the buyer (Section 3.2.2.2), we can normalize $H_k(t)$ in the following form (with $u = t/T$):

$$H_k(t) = Q_B H^*_k(u) \tag{80}$$

$$H^*_k(u) = \begin{cases} \text{if } 0 \leq u \leq s_1 \\ i/k \quad \text{if } si/T = u^*_i < u \leq u^*_{+1i} = s_{i+1}/T,\ i = 1,2,\ldots,k-1 \\ 1 \quad \text{if } sk/T = u^*_k < u \leq 1 \end{cases} \tag{81}$$

Where $u^*_1 < u^*_2 < \ldots < u^*_k$ can be considered as a random, ordered sample of the random variable U. To find the safety stock that provides the required service level, α, we have to solve the equation

$$P_\alpha (M_S) = \text{Prob}\,(H^*_k(u) \leq M_S + G^*_n(u) \quad \text{for } 0 \leq u \leq 1) = \alpha \tag{82}$$

In this form of equation (82), we can see that we have two cumulative sample distribution functions, $H^*_k(u)$, and $G^*_n(u)$, of the same random variable U (with sample sizes of k and n).

The exact distribution, P_α (M_S), can be found in Gnedenko (1951), in the case when the number of production batches, m, and the number of deliveries, n, are equal

$$P_\alpha(c/n) = 1 - \left[\frac{\binom{2n}{n+1+c}}{\binom{2n}{n}} \right] \tag{83}$$

In the case where the number of deliveries n is greater than the number of shipments per lot, k, the exact distribution, P_α (M_S), is found in Koroliuk (1955):

$$P_\alpha(c/n) = 1 - \sum_{\frac{(c+1)}{p} \leq s \leq k} \frac{\frac{c+1}{n+c+1-sp}\binom{sp+s-c-1}{s}\binom{k+n+c-sp-s}{k-s}}{\binom{k+n}{k}} \tag{84}$$

Expression (83) and (84) can be solved numerically for M_s, but it is a tedious procedure in practical applications. Therefore, we want to provide a simple approximate expression for P_α (M_n). Based on the asymptotic theory of empirical distribution functions (Smirnov, 1939; Wilks, 1967):

$$\text{Prob}\,\{\sqrt{M_s}[H_m(u) - G_n(u) \geq y \quad \text{for all } 0 \leq u \leq 1\} \rightarrow 1 - \exp\{-2y^2\}, \text{ if } M_s \rightarrow \infty \tag{85}$$

For large n values, we can consider the asymptotic expression (85) as an approximation

$$p_{\alpha}(Ms) \approx 1-\exp\left[\left(\frac{-2nk}{k+n}\right)M_s^2 n\right] \tag{86}$$

From the service level requirement of expression (70) using the above approximation, we get the following simple approximation for safety stock

$$M_s \approx \sqrt{\frac{k+n}{2kn} \ln \frac{1}{1-\alpha}} \tag{87}$$

Since $S_S = Q_B M_S$, from expression (87), we have the following simple approximation for the safety stock

$$S_s = Q_B \sqrt{\frac{1}{2}\left(\frac{1}{n}+\frac{1}{k}\right) \ln \frac{1}{1-\alpha}} \tag{88}$$

Expression (88) will be included in formulating the cost function of the supplier in Model 4 where described in Section 4.3.4. The above expression shows that the required safety stock will increase as the order size Q_B increases. In addition, the required safety stock increases with the decrease in the number of shipments (n) and the customer service level (α). The relative error of the approximation will be discussed in detail in the next chapter.

In the case of JIT supply agreement, for the same reasons presented previously, we can assume that the pattern of production follows the pattern of delivery requests. This way, $H^*_k(u)$, and $G^*_n(u)$ can be assumed to be the empirical distribution function of the same random variable U, with sample sizes k and n. P_α (M) is an order statistic since it is a function of ordered random variables, $u^*_1 < u^*_2 < \ldots < u^*_n$ distributed according to the same random variable U. Thus, the above results are valid for any distribution, U, considered (Wilks 1962). We are not restricted to the uniform distribution.

3.4 Quantifying the Joint Costs and Benefits of Adopting JIT by the Buyer and the Supplier

In a typical JIT environment, a buyer gives his engineering specifications with demand data to a potential supplier. The supplier responds with a bid price. The buyer then visits the supplier's plant to go over the bid in detail. Often the buyer and the supplier agree to adjust the specifications in a way that will lower the cost and increase the quality. This approach eliminates the annual competitive bidding process for both parties and establishes a long-term relationship. Their effective long-term relationship will eventually make any practice of frequent delivery in small lot sizes beneficial to both parties. In this scenario, it is reasonable to determine the order quantity and delivery schedule based on their total relevant joint cost rather than buyer's or supplier's individual costs. This idea of joint optimization for buyer and supplier was initiated by (Goyal 1976) and later by (Banerjee, 1986). Recently (Miller and Kelle, 1998) considered the total relevant joint costs for the case where the production lot size is equal to the shipment size, hence, m =1. In this section, we consider the joint cost of the buyer and supplier in different models under different circumstances. In the first model, we formulate the deterministic case assuming that the supplier's production lot size is equal to the shipment size ,hence, m=n . Using total joint relevant cost in model 1 as given in (Miller and Kelle, 1998) we add the shipping costs for the supplier and consider the additional cost of losing flexibility for the buyer. Since only the cases of m=1 and m=n were examined previously, we extend the model to the case where the supplier's production lot size is an integer multiple of the shipment size and m can be different from n in the second model. We expect that this extension can result substantial savings, since the supplier's production lot size, Q_S=mq, can be closer to its individual optimum

by the appropriate choice of m. The previous models in the literature allowed only the cases of $m=n$ and $m=1$.

Next, we extend the deterministic JIT approach by incorporating safety stock in the model, based on the assumption that during the transition to JIT, the buyer and supplier will agree to cooperate but problems with timing or quantity of deliveries can occur. The case where only the buyer is holding safety stock has been examined by (Kelle and Miller, 1998) . In the third model, we present the case where the buyer is holding safety stock by applying the results of (Kelle and Miller, 1998) and adding the shipping costs for the supplier and considering the additional cost of losing flexibility for the buyer. Model 4 is a new model that considers the case where the supplier is holding safety stock.

3.4.1 Model 1: Deterministic Case with Equal Number of Setups and Deliveries

For this joint model of the buyer and supplier, we have the following assumptions:

J1). We consider one supplier (producer of an item), one buyer (the retail shop for the item considered), and the customers (the final consumers of the item).

J2). The supplier has a JIT delivery agreement with the buyer to provide the required total order quantity in n shipments of equal shipment sizes at times according to the buyer's request. The supplier's production lot size Q_S is equal to the shipment size (we extend this assumption in the next section).

J3). The buyer orders a large quantity Q_B to be delivered in n equal shipments. The shipment times are scheduled according to the request of the buyer at times when it is needed by the customers.

J4). The average demand rate of the customer's demand, d_r is constant and known by the buyer.

J5). Neither the supplier nor the buyer holds safety stock

Using the same notation as in previous sections where:

A_B: total fixed cost of a purchase order,

r_B: inventory holding cost factor, the proportion of dollar value of the stock of the buyer,

Z_B: receiving cost per shipment for the buyer.

L_B : additional cost of losing flexibility per unit ordered but not delivered

p_r = production rate expressed on daily basis and

A_S = setup cost for the supplier (producer),

r_s = inventory holding cost factor (\$/\$/year),

C_S = variable cost of the finished product for the supplier,

Z_S = supplier's costs related to each shipment to the customer.

The joint total relevant cost of the buyer and supplier, in the deterministic case, when no safety stock is considered, is a function of q and n

$$JTRC_D(q,n) = \left[A_B \frac{D}{nq} + r_B C_B \frac{q}{2} + Z_B \frac{D}{q} \frac{L_B C_B nq}{2}\right] + \left[A_S \frac{D}{nq} + r_s C_s \frac{nq}{2}\left(1 - \frac{d_r}{p_r} - \frac{1}{n} + \frac{2d_r}{np_r}\right) + \frac{D}{q} Z_s\right] \tag{89}$$

Where the first term is the buyer's ordering cost, holding costs, receiving and handling cost and losing flexibility cost according to expression (6). The second term is the supplier's setup cost, holding cost and shipping cost as expressed in (61). This is an extension of Banerjee's model (1986), considering multiple deliveries and shipment cost.

The joint total relevant cost of the buyer and supplier can be expressed as

$$JTRC_D(q,n)=\frac{x_J(n)}{q}+y_J(n)q \tag{90}$$

where

$$x_J(n)=\frac{D}{n}A_B+\frac{D}{n}A_s+DZ_B+DZ_s \tag{91}$$

$$y_J(n)=\frac{r_BC_B+L_BC_Bn}{2}+\frac{r_sC_s}{2}\left(n-\frac{nd_r}{p_r}-1+\frac{2d_r}{p_r}\right) \tag{92}$$

For a given n, we can express the joint optimal value of q_J, by taking the derivative of the cost function (90) with respect to q_J, and setting it equal to 0. This yields the following expression

$$q_J^{\bullet}(n)=\sqrt{\frac{x_J(n)}{y_J(n)}}=\sqrt{\frac{\frac{2D}{n}(A_B+A_S+nZ_B+nZ_S)}{\left[(r_BC_B+L_BC_Bn)+r_sC_s\left(n-\frac{nd_r}{p_r}-1+\frac{2d_r}{p_r}\right)\right]}} \tag{93}$$

Substituting q (n) in the cost function (79) provides the minimal joint total cost as a function of n

$$JTRC_J(n)=2\sqrt{x_J(n)y_J(n))} \tag{94}$$

Relaxing the integer requirement on n, we can find the optimal n by minimizing

$$x_J(n),y_J(n)=\left[\frac{D}{n}A_B+\frac{D}{n}A_S+DZ_B+DZ_S\right]\left[\frac{r_BC_B+L_BC_Bn}{2}+\frac{r_sC_s}{2}\left(n-\frac{nd_r}{p_r}-1+\frac{2d_r}{p_r}\right)\right] \tag{95}$$

which yields

$$\frac{DA_B}{n}\left[\frac{r_BC_B}{2}+\frac{r_SC_S}{2}\left(\frac{2d_r-p_r}{p_r}\right)\right]+\frac{DA_S}{n}\left[\frac{r_BC_B}{2}+\frac{r_SC_S}{2}\left(\frac{2d_r-p_r}{p_r}\right)\right]$$

$$+\left[\frac{L_B C_B D(Z_B+Z_S}{2}\right]n+\left[\frac{r_S C_S}{2p_r}\left(\frac{p_r-d_r}{p_r}\right)\left(D(Z_B+Z_S)\right)\right]n+const. \tag{96}$$

$$=\frac{U}{n}+nV+Const.$$

with notation

$$U=DA_B\left[\frac{r_B C_B}{2}+\frac{r_S C_S}{2}\left(\frac{2d_r-p_r}{p_r}\right)\right]+DA_S\left[\frac{r_B C_B}{2}+\frac{r_S C_S}{2}\left(\frac{2d_r-p_r}{p_r}\right)\right] \tag{97}$$

and

$$V=\left[\frac{L_B C_B D(Z_B+Z_S}{2}\right]+\left[\frac{r_S C_S}{2p_r}\left(\frac{p_r-d_r}{p_r}\right)(D(Z_B+Z_S))\right] \tag{98}$$

Thus, the optimal number of deliveries can be found by taking the derivative of (96), setting it equal to 0, and expressing n from the equation as

$$n^*=\sqrt{U/V} \tag{99}$$

This n* is generally not integer. Substituting the two integer values surrounding n* into the cost function (84), we can get the best integer value of n.

3.4.2 Model 2: Deterministic Case with Different Number of Setups and Deliveries

Only the case where n=m and m=1 has been examined in the literature. This model is considered to be a new extension based the spirit of JIT partnership. Where the two parties can agree upon the shipment size q, and the buyer can choose Q_B=nq as the order quantity and the supplier can choose Q_S=mq as the lot size where n and m can be an arbitrary integer. This assumption allows both parties to adjust their order size and lot size closer to their individual optimum providing a lower total cost. Thus, the

J2*). The supplier's production lot size can be an integer multiple of the shipment size, Q_S = mq. Thus, the number of deliveries n of a buyer's order Q_B= nq can be different from the number of setups.

The joint total relevant cost (JTRC) of the buyer and supplier can be expressed as in the previous section. The difference here is that we have three decision variables, q, n, and m.

$$JTRC(q,n,m)=\frac{x_J(n,m)}{q}+y_J(n,m)q \tag{100}$$

with notation

$$x_J(n,m)=\frac{D}{n}A_B+\frac{D}{m}A_S+DZ_B+DZ_S \tag{101}$$

$$y_J(n,m)=\frac{r_BC_B+L_BC_Bn}{2}+\frac{r_SC_S}{2}\left(m-\frac{md_r}{p_r}-1+\frac{2d_r}{p_r}\right) \tag{102}$$

For a given n and m, we can express the optimal value of q_J, by taking the derivative of the cost function (100) with respect to q_J, and setting it equal to 0. It yields the following expression

$$q_J^*(n,m)=\sqrt{\frac{x_J(n,m)}{y_J(n,m)}}=\sqrt{\frac{2D(\frac{A_B}{n}+\frac{A_S}{m}+Z_S)}{r_BC_B+L_BC_Bn+\left[r_SC_S\left(m-\frac{md_r}{p_r}-1+\frac{2d_r}{p_r}\right)\right]}} \tag{103}$$

Substituting q (n, m) in the cost function (100) provides the total cost as a function of n and m

$$JTRC_J(n,m)=2\sqrt{(x_J(n,m)y_J(n,m))} \tag{104}$$

As in Model 1, by relaxing the integer requirement on n and m, we can find the optimal n and m by minimizing $x_J(n,m)$ $y_J(n,m)$.

As in Model 1, by relaxing the integer requirement on n and m, we can find the optimal n and m by minimizing $x_J(n,m)\ y_J(n,m)$.

$$xJ(n,m)yJ(n,m)=\left[\frac{D}{n}A_B+\frac{D}{m}A_S+DZ_B+DZ_S\right]\left[\frac{r_BC_B+L_BC_Bn}{2}+\frac{r_SC_S}{2}\left(m-\frac{md_r}{p_r}-1+\frac{2d_r}{p_r}\right)\right]$$

(105)

which yields

$$\frac{DA_B}{n}\left[\frac{r_BC_B}{2}+\frac{r_SC_S}{2}\left(\frac{2d_r-p_r}{p_r}\right)\right]$$

$$+\left[\frac{L_BC_BD(Z_B+Z_S)}{2}\right]n+\left[\frac{r_SC_S}{2p_r}\left(\frac{p_r-d_r}{p_r}\right)(D(Z_B+Z_S))\right]m+\frac{L_BC_BDA_S}{2}\frac{n}{m}+$$

$$+\frac{r_SC_SDA_B(p_r-d_r)}{2p_r}\frac{m}{n}+Const. \tag{106}$$

$$=\frac{U_1}{n}+\frac{U_2}{m}+U_3n+U_4m+U_5\frac{n}{m}+U_6\frac{m}{n}+Const. \tag{107}$$

with notation

$$U_1=DA_B\left[\frac{r_BC_B}{2}+\frac{r_SC_S}{2}\left(\frac{2d_r-p_r}{p_r}\right)\right]$$

$$U_2=DA_S\left[\frac{r_BC_B}{2}+\frac{r_SC_S}{2}\left(\frac{2d_r-p_r}{p_r}\right)\right]$$

$$U_3=\left[\frac{L_BC_BD(Z_B+Z_S}{2}\right]$$

$$U_4=\left[\frac{r_SC_S}{2p_r}\left(\frac{p_r-d_r}{p_r}\right)(D(Z_B+Z_S))\right]$$

$$U_5=\frac{L_BC_BDA_S}{2}$$

$$U_6=\frac{r_SC_SDA_B(p_r-d_r}{2p_r}$$

$$n^*(m)=\sqrt{\frac{U_1+U_6 m}{U_3+U_{5/m}}} \quad and \quad m^*(n)=\sqrt{\frac{U_2+U_5 n}{U_4+U_{6/n}}} \tag{108}$$

For the solution we need to use numerical methods, discussed in the next chapter.

3.4.3 Model 3: Transition to JIT When the Buyer Is Holding Safety Stock

The previous two models consider the case where, the buyer and supplier operate in a deterministic environment, neither the buyer nor the supplier has to hold safety stock. In fact, there is always uncertainty in the customer's demand, but flexible resources and short production and supply lead times enable the required service level to be met in this case without holding safety stocks. Usually in practice, however, the appropriate flexibility and capacity are not available or too expensive to maintain. We call this stage the time of transition to JIT supply.

In this transition stage, which can be long, safety stock has to be held to provide the appropriate service level. Therefore, we extend the deterministic JIT approach by incorporating into the model the safety stock expression in Kelle (1984) and Kelle and Schneider (1992) into the joint total relevant cost and thus, derive the optimal order quantity and number of shipments under different scenarios. This model presents the situation when the supplier is not reliable, or is unable to provide small, frequent deliveries on time with established quantity or quality levels. The study incorporates the safety stock into the model under the situation of "not quite JIT" where the buyer and supplier are in transition to JIT supply and the buyer holds a safety stock. This case was examined previously by (Kelle and Miller, 1998). The difference is that this model is adjusted by adding the shipping costs for the supplier and cost of losing flexibility for the buyer.

The first three assumptions are the same (J1, J2*, and J3) as in the previous section for Model 2. The last two assumptions (J4 and J5) are replaced by the following assumptions:

J4)*. The demand has a known average rate, d_r. The demand rate is changing according to the customer's request which is unknown at the time of safety stock planning.

J5)*. The *shipment times* are independent identically distributed (i.i.d.) random variables in (0, T), arranged in ascending order $t_1 \le t_2 \le \ldots \le t_n$. The supplier tries to follow the pattern of the demand according to the JIT supply agreement, but because of production, capacity, or transportation problems there are random disturbances in the delivery times

J6). Safety stock will be held by the buyer to protect against any random delays in shipments.

In section 3.2.2.2, we derived the following simple approximation for the required safety stock, S_B, which provides the service level α

$$S_B = QB\sqrt{\frac{\ln\left(\frac{1}{1-\alpha}\right)}{2n}} \tag{109}$$

We incorporate the expected holding cost of safety stock

$$r_B\, C_B\, S_B \tag{110}$$

into the joint total relevant cost and derive the optimal order quantity and number of shipments, n. Using the previous notation, $Q_B = nq$,

$$JTRC(q,n,m)=\frac{x_J(n,m)}{q}+y_J(n,m)q \tag{111}$$

where

$$x_J(n,\ m)\ =\ \frac{D}{n}A_B+\frac{D}{m}A_S+DZ_B+DZ_S \tag{112}$$

$$y_J(n,\ m)\ =\ \frac{r_B C_B+L_B C_B n}{2}+\frac{r_S C_S}{2}\left(m-\frac{md_r}{p_r}-1+\frac{2d_r}{p_r}\right)$$

$$+r_B C_B n\left(\sqrt{\frac{1n\left(\frac{1}{1-\alpha}\right)}{2n}}\right) \tag{113}$$

For a given k and m, we can express the optimal value of q_J in a similar form to (103),

yielding the following expression

$$q_J^*(n,m)=\sqrt{\frac{xJ(n,m)}{yJ(n,m)}}$$

$$=\sqrt{\frac{2D\left(\frac{A_B}{n}+\frac{A_S}{m}+Z_B+Z_S\right)}{r_B C_B+L_B C_B n+\left[r_S C_S\left(m-\frac{md_r}{p_r}-1+\frac{2d_r}{p_r}\right)\right]+\left[r_B C_B n\left(\sqrt{\frac{1n\left(\frac{1}{1-\alpha}\right)}{2n}}\right)\right]}} \tag{114}$$

Substituting q^*_J (n, m) in the cost function (111) provides the total cost as a function of n and m

$$JTRC_J(n,m)=2\sqrt{(x_J(n,m)y_J(n,m))}$$

$$=2\sqrt{\left[\frac{D}{n}A_B+\frac{D}{m}A_S+DZ_B+DZ_S\right]}$$

$$\left[\frac{r_B C_B+L_B n}{2}+\frac{r_S C_S}{2}\left(m-\frac{md_r}{p_r}-1+\frac{2d_r}{p_r}\right)+r_B C_B n\left(\frac{ln\left(\frac{1}{1-\alpha}\right)}{2n}\right)\right] \quad (115)$$

For the solution we need to use a numerical methods, discussed in the next chapter.

3.4.4: Model 4: Transition to JIT When the Supplier Is Holding Safety Stock

Only the case where the buyer is holding safety stock has been examined previously by (Kelle and Miller, 1998a). We provide a new model where the supplier is holding safety stock under transition to JIT. In the spirit of JIT, the study derives the minimum safety stock needed in order to protect against shortages that may be caused by delivery delays. The safety stock that is required to provide the appropriate customer service level depends on the number of shipments and the shipment size. The proposed model determine the optimal values of the three decision variables, the shipment size, the number of shipments and safety stock

All assumptions are the same as for Model-3 except the last assumption (J6) which is modified as

J6)*. Safety stock will be held by the supplier to meet the buyer's shipment request, with the required service level, α, on time according to JIT delivery agreement.

The supplier's required safety stock, to provide the required service level, is approximated according to section 3.3.3.1 as

$$S_S = Q_B\sqrt{\frac{1}{2}\left(\frac{1}{n}+\frac{1}{k}\right)ln\frac{1}{1-\alpha}} \quad (116)$$

As in the previous section, the joint total relevant cost (JTRC) of buyer and supplier, including the expected holding cost of the safety stock of the supplier and (n=km where k is integer) can be expressed as

$$JTRC(q,k,m)=\frac{x_J(k,m)}{q}+y_J(m)q \tag{117}$$

where

$$x_J(k,m)=\frac{D}{km}A_B+\frac{D}{m}A_S+DZ_B+DZ_S \tag{118}$$

$$y_J(m)=\frac{r_BC_B+L_BC_Bkm}{2}$$

$$+\frac{r_SC_S}{2}\left[2km\left(\sqrt{\frac{1}{2}\left(\frac{1}{km}+\frac{1}{k}\right)ln\left(\frac{1}{1-\alpha}\right)}\right)+m-\frac{md_r}{p_r}-1+\frac{2d_r}{p_r}\right] \tag{119}$$

For a given k and m, we can express the optimal value of q_J in a similar form to (114), yielding the following expression

$$q_J^*(k,m)=\sqrt{\frac{x_J(k,m)}{y_J(k,m)}}=$$

$$\sqrt{\frac{\frac{D}{km}(A_B+kA_S+kmZ_B+kmZ_S}{\left[\frac{r_BC_B+L_BC_Bkm}{2}+\frac{r_SC_S}{2}\left(\sqrt{\frac{1}{2}\left(\frac{1}{km}+\frac{1}{k}\right)ln\left(\frac{1}{1-\alpha}\right)}+m-\frac{md_r}{p_r}-1+\frac{2d_r}{p_r}\right)\right]}} \tag{120}$$

Substituting q (k, m) in the cost function (117) provides the total cost as a function of k and m

$$JTRC_J(k,m)=2\sqrt{(x_J(k,m)y_J(k,m))}$$

$$=2\sqrt{\frac{D}{km}(A_B+k\,A_S+km\,Z_B)\frac{r}{2}\left[\frac{r_BC_B+L_BC_Bn}{2}\right]}$$

$$+\left(2km\left(\sqrt{\frac{1}{2}\left(\frac{1}{km}+\frac{1}{k}\right)ln\left(\frac{1}{1-\alpha}\right)}\right)+m-\frac{md_r}{P_r}-1+\frac{2d_r}{P_r}\right)\Bigg] \qquad (121)$$

For the solution we need to use numerical methods, discussed in the next chapter.

CHAPTER 4
NUMERICAL AND MANAGERIAL ANALYSIS

4.1 Introduction

In the previous chapters we discussed and quantified the potential costs and benefits of a long-term relationship between the buyer and the supplier in a JIT environment. In this chapter we present numerical solutions, examples, and sensitivity analysis followed by a managerial analysis of the JIT partnership in different situations.

In each situation, we consider three typical cases in our managerial analysis:

a.) **supplier's dominance**, with large production lot sizes and shipment sizes;

b.) **buyer's dominance** with small, frequent, timely shipments;

c.) **buyer and supplier have equal power in negotiation**.

In each case, we compare the optimal ordering policy of the dominating party to the joint optimal ordering policy and provide a quantitative tool for the negotiation between the parties. The savings and loss for each party are computed that provides the quantitative support for negotiation, compromise, and compensation.

The chapter is divided into four sections. Following the introduction, Section 4.2 considers the case where the buyer and supplier operate in a deterministic environment and neither the buyer nor the supplier has to hold safety stock. This can be the rare situation when the demand and supply are deterministic. In practice, there is always uncertainty in the customer demand. These demand fluctuations can be disregarded and no safety stock is required if the supplier has flexible resources and enough capacity to provide a reliable JIT supply. We call this situation as "perfect

JIT supply". The quantitative models for these situations have been formulated in Sections 3.4.1 and 3.4.2.

Section 4.3 deals with numerical and managerial analysis for the case of uncertainty. First, we examine the effect of increasing demand uncertainty on the required amount of flexible resources and its consequence of increasing production cost. This is the numerical analysis of the model described in Section 3.3.1. In many cases, the suppliers don't have enough flexible capacity to meet the randomly changing demand of the buyer or it is too expensive. We call this stage as the time of "transition to JIT supply". For this stage, safety stock is required to provide the appropriate customer service. The safety stock can be hold either by the buyer or by the supplier. We analyze both cases in the second part of this section. The quantitative models to the two cases have been formulated in Section 3.4.3 and Section 3.4.4.

Section 4.4 provides the numerical and managerial comparison of the four basic models: the two deterministic models (Model 1for the case n equals m and Model 2 for the case n not equal m); the two Uncertainty models (Model3 for the buyer's safety stock case, and Model 4 the supplier's safety stock case.

The numerical analysis will seek the following values, where it is relevant:

The optimal shipment size for the buyer and supplier individually and jointly q*

Optimal number of shipments, n

Buyer's optimal order quantity, Q^*_B

Supplier's optimal production lot size, Q^*_S

Optimal number of shipments per lot size, m

Optimal safety stock held by the buyer, S^*_B

Optimal safety stock held by the supplier, S^*_S

Optimal total relevant joint costs under the three typical cases (supplier's dominance, buyer's dominance, and buyer and supplier have equal power), TRC

For the sake of comparison we are going to use the same values as a base-case example for the following parameters introduced in the previous section

D	= 1000 unit/year (demand rate, $d_r = 1$)
P	= 2500 unit/year (production rate, p_r=2.5)
A_B	= \$150/order (buyer's ordering cost)
A_S	= \$200/setup (supplier's setup cost)
C_B	= \$20/uint (selling price)
C_S	= \$10/unit (production cost)
r_B	= 0.25 (buyer's annual inventory carrying cost rate)
r_S	= 0.35 (supplier's annual inventory carrying cost rate)
Z_B	= \$2/shipment (receiving cost for the buyer)
Z_S	= \$3/shipment (supplier's cost related to each shipment to buyer)
L_B	= 0.02 (cost of losing flexibility for the buyer)

4.2 Numerical and Sensitivity Analysis for the Case of no Safety Stock

In this section we investigate two scenarios, in the first scenario we consider the joint economic order model with constant demand rate and assume that each order is produced in one setup and delivered in one shipment. This is the base case of traditional supply with no JIT consideration. The scenario is extended to multiple deliveries of a purchase order and to production lot sizes of a multiple of the

shipment size. This is the typical JIT supply scenario for which the quantitative models are discussed in sections 3.4.1 and 3.4.2. First we illustrate the costs, tradeoffs, and managerial implications on a numerical example of the base-case parameter values introduced in the previous section. We provide thereafter a detailed sensitivity and managerial analysis.

4.2.1. Case of no JIT Supply

Using the total relevant cost expression (4) of the buyer, the optimal order quantity is, Q_B^* = 263 and the optimal total relevant cost, TRC_B (Q_B) = \$1157, for the buyer (the results are summarized in Table 4.1 and illustrated in Figure 4.1.). If the supplier has the lot size of 263, required by the buyer, the supplier's cost is TRC_S (Q_B^*) = \$956. Therefore, the total system cost is \$2113. Similarly, from the supplier's total relevant cost expression, (54), we calculate the supplier's optimal lot size, Q_S^* = 538 and the supplier's costs, TRC_S (Q^*_S) = \$754. If the supplier is more powerful and forces the buyer to order in the lot size of 538, the buyer's cost is TRC_B (Q_S^*) = \$1146. In this case, the total system cost is much higher, \$2220.

Table 4.1
Optimal Ordering Policies and Relevant Costs for the Base-Case Parameters with no JIT Consideration

Policy	Buyer's Optimal	Supplier's Optimal	Joint Optimal
Order Quantity	263	538	350
Buyer's Cost	1157	1466	1204
Supplier's Cost	956	754	825
Total Joint Cost	2113	2220	2029
Buyer's Loss	0	310	48
Supplier's Cost	202	0	71
Total Loss	202	310	119

From equation (77), using one shipment to each order (n=1), we can get the optimal joint order quantity $Q_J^* = 350$. If the two parties accept the joint order quantity and lot size of 350, the total costs for the buyer is $TRC_B(Q_J^*) = \$\ 1204$, for the supplier, $TRC_S(Q_J^*) = \$825$, and the total system cost is the minimum, \$2029. Thus, the total system cost can be decreased by \$84 (5%) if the two parties are ready to switch from the buyer's optimal policy to the joint optimal policy. Similarly, the total system gain is \$191 (10%) by switching from the supplier's optimal policy to the joint optimal policy.

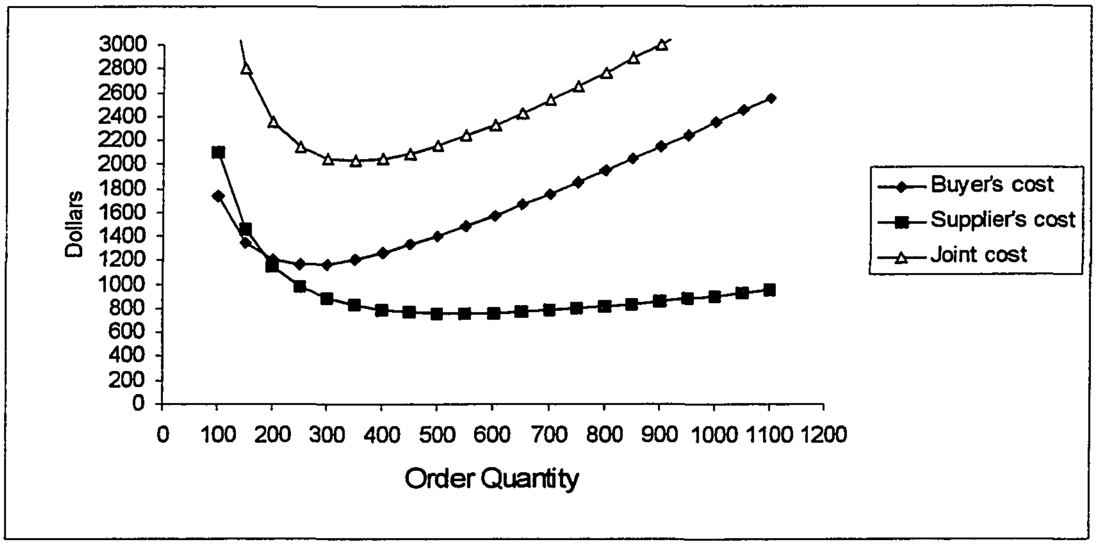

Figure 4.1
Total System Costs and Individual Costs
for the Buyer and the Supplier for Different Order Quantities

If the strong buyer forces its optimal policy on the supplier, the supplier's loss is \$ 202 compared to its optimal cost. On the other hand, if the strong supplier forces its optimal policy on the buyer, the buyer's loss is \$ 310. If the buyer and supplier are willing to compromise and accept the joint optimal policy, the buyer's

loss and supplier loss are \$ 48 and \$ 71 respectively and that provides the best scenario with the minimal total loss of \$119. The information is summarized in Table 4.1. Figure 4.1 shows the cost function for the buyer, for the supplier, and for the total system. It demonstrates that the cost functions are convex and the lowest system cost occurs at $Q_J^* = 311$ between the two values of $Q_B^* = 214.5$ and $Q_S^* = 506.2$.

Next we examine the three different scenarios in negotiation using the above numerical example.

a.) If the **supplier is strong**, the buyer has \$ 310 (21%) loss compared to its optimal cost (see in Table 4.1) by using the supplier's optimal lot size as order quantity. The buyer is willing to negotiate with the supplier for accepting smaller order quantities that would decrease the buyer's cost. The closer the buyer can get to its optimal order quantity, the more is the inventory cost decrease for the buyer. The same time, however, the supplier has higher and higher costs (see Figure 4.1) that must be compensated by the buyer in the form of a higher purchase price or in the form of a premium. The buyer, knowing its own cost factors, can calculate the cost decrease due to decreased order quantity and can make an offer to the supplier. The supplier can also calculate its cost increase based on its own cost factors, and accept the offer or negotiate higher compensation. The tools, provided in Chapter 3, enable both parties to evaluate the different tradeoffs. As we can see from Figure 4.1, in each case there is a possibility to improve the total system cost by choosing a compromise in order quantity/ lot size. The best deal is the joint optimal order quantity that can be calculated if the two parties are ready

to cooperate and share their information. Even though the supplier's cost would be higher, the buyer can compensate it and still have lower total costs. In this example, the buyer's would experience a 17%(Bben%) decrease in cost after compensating the supplier's loss. The percentage benefit for the buyer, Bben%, is expressed in percent relative to the buyer's original cost in Table 4.2

Table 4.2
Moving from Supplier's Optimal to Joint Optimal

	Buyer's Cost	Supplier Cost	Total Cost
Supplier Optimal	1466	754	2220
Joint Optimal	1204	825	2029
Cost Improvement	262	-71	191
Compensation	-71	71	0
Buyer Benefit	191		
Bben%	17%		

b.) If the **buyer is strong**, the supplier will be urged to accept the buyer's optimal order quantity. The supplier is willing to make some sort of concession, such as price discount, to the buyer to encourage the latter to accept the joint order quantity. Table 4.3 shows the net gain that can be achieved by the supplier if the buyer will agree to order the joint optimal order quantity. In this example, the supplier would experience a 9% decrease in a cost. this quantity, the supplier's benefit, is denoted by Sben% and it is expressed in percent relative to the supplier's original cost in Table 4.3.

Table 4.3
Moving from Buyer's Optimal to Joint Optimal

	Buyer's cost	Supplier cost	Total cost
Buyer's optimal	1157	956	2113
Joint Optimal	1204	825	2029
Cost Improvement	-48	131	83
Compensation	48	-48	0
Supplier Benefit		83	
Sben%		9%	

c.) If **both parties are equally strong**, they can agree to follow the optimal joint policy and share on the joint benefit which is in the range of 5.6% to 10.2% in this numerical example.

Now, we evaluate the tradeoff among system parameters (e.g., holding cost, setup costs, and ordering costs) of the partners in greater detail and examine how these tradeoffs affect the joint optimum. Such study gives insight into how changes in the system parameters or error in parameter estimation affect the joint order quantity.

For the no JIT model we can express the buyer's and supplier's setup cost rate, ordering cost rate and holding cost rate, demand and production rate in the following ratios:

$\alpha = A_B / A_S$, where $0 < \alpha < \infty$ (ordering costs vs. setup cost)

$\beta = C_B / C_S$, where $0 < \beta < \infty$ (holding costs ratio),

$\gamma = D/P$, where $D < P$ (utilization rate),

Since we assume that the buyer's purchase price C_B will always be greater than the supplier's production cost C_S and if the holding cost rates are identical, the

holding cost ratio will always be greater than one. For the sake of simplicity, here we assume that the holding cost rates are the same and use $r_S = r_B = 0.25$

In Chapter 3 (assuming one single delivery for each order m=1), we have the joint total relevant cost

$$JTRC(Q_J) = A_B \frac{D}{Q_J} + rC_B \frac{Q_J}{2} + A_S \frac{D}{Q_J} + rC_S \frac{DQ_J}{2P} \tag{122}$$

We rewrite equation (122) so that the costs are expressed in terms of the above ratios to yield:

$$JTRC(Q_J) = \frac{DA_B}{Q_J}(1 + \frac{A_S}{A_B}) + \frac{Q_J rC_B}{2}(1 + \frac{D}{P}\frac{C_S}{C_B}) \tag{123}$$

After substituting α, β, and γ into (123), we have the following expression:

$$JTRC(Q_J) = \frac{DA_B}{Q_J}(1 + \frac{1}{\alpha}) + \frac{Q_J rC_B}{2}(1 + \gamma(\frac{1}{\beta})) \tag{124}$$

In order to study the effects of the tradeoffs in holding, setup, and demand rates; we find the value of Q_J that minimizes (124)

$$Q_J^* = \sqrt{\frac{2DA_B}{rC_B}\frac{(1 + \frac{1}{\alpha})}{(1 + \gamma(\frac{1}{\beta}))}} \tag{125}$$

To determine how the joint solution varies with respect to the above ratios, we take the partial derivative of (125) with respect to α, β, and γ to yield

$$\frac{\partial Q_J}{\partial \alpha} = -\frac{1}{2}(1+\frac{1}{\alpha})^{-\frac{1}{2}}\frac{1}{\alpha^2} * C < 0 \qquad (126)$$

$$\frac{\partial Q_J}{\partial \beta} = +\frac{1}{2}(1+\gamma(\frac{1}{\alpha}))^{-\frac{3}{2}}\gamma\beta^{-2} * C > 0 \qquad (127)$$

and

$$\frac{\partial Q_J}{\partial \gamma} = -\frac{1}{2}(1+\gamma(\frac{1}{\alpha}))^{-\frac{3}{2}}\frac{1}{\beta} * C < 0 \qquad (128)$$

Where C, represents the remaining positive constants unaffected by a change in the ratio under study. The sign of partial derivative indicates how the joint solution varies with respect to the particular variable. Equation (126) indicates that the joint order quantity decreases when the ordering cost increases relative to the setup cost. Equation (127) suggests that the joint order quantity increase as the purchase price increases relative to the production cost, and equation (128) indicate that the order quantity decreases as the demand rate increases relative to the production rate.

To further illustrate the cost tradeoffs, we use the cost information from the example in section 4.2.1, for which $\alpha = 0.75$, $\beta = 2$, and $\gamma = 0.4$. We have the joint optimal solution, Q_{Jo}^* , of 350 units, and the joint total costs, JTRC (Q_{Jo}^*) , of \$ 2029. Tables 4.4, 4.5 and 4.6 show the percentage costs changes, { JTRC (Q_J^*) – JTRC (Q_{Jo}^*) } / JTRC (Q_{Jo}^*) * 100%, and the joint order quantities at different levels of α , β , and γ. The tables confirm the previously stated relationships between the joint order quantity and the ratios.

Understanding how these parameters affect the joint order quantity is important when companies are planning to make investment in process improvement. We see from the above analysis that if the suppliers want to increase the joint order quantity they can focus in reducing production costs or increasing the

Table 4.4
Percentage Cost Changes at 0.5 γ with Changes in α and β and the Joint Order Quantity

	0.5 α		α		2 α	
	% Cost	Q_J^*	% Cost	Q_J^*	% Cost	Q_J^*
0.5 β	32.16	405.7	-2.8	360.7	-35.54	249.8
β	28.27	418.2	-5.13	372.3	-38.52	279.6
2 β	26.69	432.1	-7.80	383.9	-39.58	285.1

Table 4.5
Percentage Cost Changes at γ with Changes in α and β and the Joint Order Quantity

	0.5 α		α		2 α	
	% Cost	Q_J^*	% Cost	Q_J^*	% Cost	Q_J^*
0.5 β	49.96	405.9	12.54	365.1	-15.15	203.8
β	37.16	446.7	0.00	350	-22.54	229.8
2 β	29.28	455.7	-5.13	365	26.51	245.6

Table 4.6
Percentage Cost Changes at 2 γ with Changes in α and β and the Joint Order Quantity

	0.5 α		α		2 α	
	% Cost	Q_J^*	% Cost	Q_J^*	% Cost	Q_J^*
0.5 β	73.71	362.3	28.49	216.2	-15.15	175.9
β	49.97	397.9	10.54	276.1	-2.02	197.8
2 β	36.16	466.7	6.8	331	-27.54	250.8

production rate. Investment can be made in new equipment, in eliminating waste in the production process or in improving the design for ease of manufacturing. Buyers on the other hand, can decrease the joint order quantity by negotiating a better price

from the supplier or by increasing the demand for the end product. The partners will want to increase or decrease the joint order quantity to move it closer to their individually optimal order sizes.

The faster the buyer's order can be made and the closer the buyer's ordering cost is to the supplier's setup cost, the lower are the joint total relevant costs. In a cooperative relationship one way the partners can work together to improve the supplier's production process is to increase the production rate and reduce setup times, thereby reducing setup costs. The holding costs do have effects on the total system costs, but the effects are not consistent.

4.2.2. Case of JIT Supply

In JIT supply, small frequent deliveries are required. We assume that the buyer's order, Q_B, is delivered in n shipments of equal size $q = Q_B/n$. The supplier's production lot size can also be an integer multiple of the shipment size, $Q_S = mq$, and m can be different from n .

First, we consider a numerical example with the same parameters as in the previous section to compare the non-JIT case and two different JIT models. The first JIT model (Model 1 in Section 3.4.1), that was published by Miller and Kelle (1998), assumes that the supplier's production size Q_S is equal to the shipment size q. The second JIT model (Model 2 in Section 3.4.2), is our extension to the case where n and m can be different, thus allowing different order quantity and lot size. This additional flexibility may provide considerable cost savings.

We use the results of Section 3.2.1 to find the buyer's optimal policy. There we saw that the buyer's total relevant cost is decreasing with increasing Q_B and n,

according to expression (5). This result shows the tendency of JIT to have a long supply contract and deliver frequently in small shipment sizes, q. It can be seen that the optimal n for the buyer is infinity. This result has not yet been published in the quantitative literature, however it supports the tendency in practice of having very long purchase order contracts in the JIT supply agreements so saving on ordering costs without increasing the holding costs.

The cost improvement is marginally decreasing as the order quantity increases. For the order quantity, there is a reasonable, managerial limit where the loss of flexibility, and concerns of product changes and long commitments outweigh the annual ordering cost decrease. We assume that the part of the order quantity that is not delivered to the buyers is a commitment that must be bought in the future. This commitment results in a loss of flexibility for changes. Therefore, we introduced a new cost parameter in Section 3.2.1. that will consider the managerial concern of having too large order quantity Q_B . We check the effect of this new cost parameter with the other parameter changes in our sensitivity and managerial analysis.

From expression (81) and (85), we find the optimal values for shipment size, q, and the value of n respectively. These results have been published in the literature (Miller and Kelle, 1998). The difference is that we add the shipping costs for the supplier and consider the additional cost of losing flexibility for the buyer. The numerical and cost results for the base-cease parameter set described in Section 4.1 are summarized in Table 4.7. Compared to the non-JIT policy results of Table 4.1, we see a large cost improvement resulted by switching to JIT policy. The cost

improvement is 24.8% if the buyer's optimal policy is followed, 8.3% if the supplier's optimal policy is followed and it is 25.1% for the joint optimal policy.

From equation (85), we can get the optimal number of shipments n=m=16 and the optimal shipment size $q_J^* = 35$. If the two parties accept the joint shipment size, the total costs for the buyer is $TRC_B(q_J^*) = \$\ 509$, for the supplier, $TRC_S(q_J^*) = \$\ 1010$, and the total system cost is the minimum, \$ 1519. Thus, the total system cost can be decreased by \$ 71 (5%) if the two parties are ready to switch from the buyer's optimal policy to the joint optimal policy. Similarly, the total system gain is \$ 516 (35%) by switching from the supplier's optimal policy to the joint optimal policy.

Table 4.7
Optimal Ordering Policies and Relevant Costs for Model 1
Using the Base-Case Parameters

Policy	Buyer's Optimal	Supplier's Optimal	Joint optimal
Number of shipment per order n	30	-	16
Number of shipment per lot size m	-	1	16
Shipment size q	28	539	35
Order quantity Q_B	840	-	560
Production lot size Q_S	-	539	560
Buyer's TRC	488	1281	509
Supplier's TRC	1101	754	1010
Overall TRCJ	1589	2035	1519
Buyer's Loss	0.00	163%	4%
Supplier's loss	46%	0.00	34%

Next we examine the new extension (Model 2) where we assume, that the buyer's order, Q_B, is delivered in n shipments of equal size $q = Q_B/n$. The supplier's

production lot size can also be an integer multiple of the shipment size, $Q_S = mq$, and m can be different from n.

If the buyer is strong and forces its optimal shipment size and frequency to the supplier. The number of shipment is 30 and the shipment size is 28. The numerical and cost results are summarized in the first column of Table 4.8. The buyer's total cost is \$ 488 and using the buyer's optimal the supplier total cost is \$ 1101.

If the supplier is strong, then the supplier can chose its best lot size as an integer multiple of the shipment quantity, $Q_S = mq_B$. In the numerical example, for the demand and production rate we have the relation $2d_r < p_r$, thus m=1 for the supplier's optimal policy, and Q_S can be expressed by (62). The numerical and cost results are summarized in the second column of Table 4.5. It shows that the optimal shipment size for the supplier is 539 and the supplier's total cost is \$ 754. The buyer must accept the optimal lot size of the supplier, $Q_S = q_S$ as the shipment size, the buyer's total cost is \$ 1281.

For the joint optimal policy of the two parties we use the results of Section 3.4.2. From expression (81) and (85), we find the optimal values for shipment size, q, and the value of n and m respectively using an iterative calculation. The optimal value of n and m are 23 and 12 respectively. The optimal shipment size $q_J^* = 38$. If the two parties accept the joint shipment size, the total costs for the buyer is $TRC_B(q_J^*)$ = \$ 494, for the supplier, $TRC_S(q_J^*)$ = \$ 982, and the total system cost is the minimum, \$ 1476. Thus, the total system cost can be decreased by \$ 114 (7%) if the two parties are ready to switch from the buyer's optimal policy to the joint

optimal policy. Similarly, the total system gain is $ 558 (27%) by switching from the supplier's optimal policy to the joint optimal policy.

Table 4.8
Optimal Ordering Policies and Relevant Costs for Model 2
Using the Base-Case Parameters

Policy	Buyer's Optimal	Supplier's Optimal	Joint optimal
Number of shipment per order n	30	-	23
Number of shipment per lot size m	-	1	12
Shipment size q	28	539	38
Order quantity Q_B	840	-	874
Production lot size Q_S	-	539	456
Buyer's TRC	488	1281	494
Supplier's TRC	1101	754	982
Overall TRCJ	1589	2035	1476
Buyer's Loss	0.00	163%	1%
Supplier's loss	46%	0.00	30%

As in the previous section we examine the three different scenarios in negotiation, now considering the JIT supply case.

a.) If the **supplier is strong**, the buyer is willing to negotiate with the supplier for accepting the joint order quantity to minimize the loss that incurred by using the supplier's optimal lot size as shipment quantity. The buyer's compensation should be larger in this case than in the non-JIT case (Table 4-2), still the benefit for the buyer is larger. The buyer could have a cost decrease up to $ 559 (44%) after compensating the supplier for its loss. The costs are summarized in Table 4.9 for the different cases including the percentage benefit for the buyer, Bben%.

Table 4.9
Moving from Supplier's Optimal to Joint Optimal

	Buyer's Cost	Supplier Cost	Total Cost
Supplier Optimal	1281	754	2035
Joint Optimal	494	982	1476
Cost Improvement	787	-228	558
Compensation	-228	228	0
Buyer Benefit	559	0	559
Bben%	44%		

b.) Similarly, let examine the case where the **buyer is stronger** than the supplier. The supplier is willing to make some sort of concession, such as price discount, to the buyer to encourage the latter to accept the joint order quantity. The supplier could have a cost decrease up to $ 114 after compensating the buyer for its loss. So , the percentage benefit for the supplier ,Sben%, is 10%. Table 4.10 shows that compensation amount and the net gain that can be achieved by the supplier is smaller in this case as in the case of no JIT supply (Table 4.3). This numerical result seems to indicate that the joint optimal policy is close to the buyer's optimal policy in the case of JIT consideration. We will explore this issue later on in more details considering several different parameters.

Table 4.10
Moving from Buyer's Optimal to Joint Optimal

	Buyer's Cost	Supplier Cost	Total Cost
Supplier Optimal	488	1103	1591
Joint Optimal	494	983	1477
Cost Improvement	-6	120	114
Compensation	6	-6	0
Supplier Benefit	0	114	114
Sben%		10%	

c.) If the **buyer and supplier willing are equally strong**, they can agree to adjust their policy to the optimal joint policy and share the joint benefit. Only a very small gain (2%) can be achieved relative to the buyer's optimal policy in this numerical example but the gain is larger (30%) relative to the supplier optimal policy. We will explore this issue later on in more details considering several different parameters. We note that the joint optimal policy is close to the buyer's optimal policy of frequent, small shipments, which also supports the advantages of JIT deliveries.

After the numerical and managerial analysis of the solution for the base-case set of parameters we provide next a sensitivity analysis. We evaluate the effect of cost parameters giving insight into how the changes in the cost parameters or error in parameter estimation affect the joint optimal solution. Specifically, the changes in the joint optimal shipment size, q_j, the total relevant cost for the joint optimal policy, TRC_j, are considered first.

Next the effect of parameter changes on the cost savings achieved by using the joint optimal policy are investigated.

The buyer's benefits, **Bben%**, expresses the percent cost improvement achieved by the buyer (after compensating the supplier's loss) by switching from the supplier's optimal policy to the joint optimal policy. Similarly, the supplier's benefit, **Sben%**, expresses the supplier's percent cost improvement by switching form the buyer's optimal policy to the joint optimum. .

We modify the base-case parameter set, one parameter at a time. The number of the relevant cost parameters is large (11), thus we have considered only the

single-factor effects. We figure out the percent increase or decrease in the joint optimal solution compared to the base-case solution by changing the cost parameters. We increase the cost parameters by 50% and 25% and decreasing them by the same rate. For the base-case parameters, the values for the optimal solution are $q^* = 38$, $TRC^* = 1476$, and the percent benefits are $Bben^* = 44\%$ and $Sben^* = 10\%$. Table 4.11 summarizes the percentage increase or decrease in the optimal solution for different percent changes in the cost parameters.

Further analyses have been made to identify the cost parameters that have the most significant effect on the joint optimal solution. The numerical results reveal that the inventory holding cost for the buyer, r_b, and the selling price, C_B, are the most influential cost parameters on the joint optimal shipment size, q_j. The two cost parameters, rb and C_B have almost the identical effect on the shipment size q. If we increase either one of them, the shipment size q_j will decrease. These results are available in previous research. The form of the relation is illustrated in Figure 4.2. The regression analysis , based on a larger set of parameter changes, shows a quadratic relation between the change in r_b and the resulting change in q_j:

$$q_j\% = 0.546\, r_b\% - 0.6822\, r_b\% - 0.006 \tag{129}$$

with $R^2 = 0.998$.

Also, we find that the setup cost for the supplier, A_S, and inventory holding cost of the supplier, r_s, are causing the highest incremental changes in the joint optimal value of the total relevant cost, TRC_j. The two cost parameters have identical effect on the total relevant cost. The cost increase is close to linear with the increase of the cost parameters as it is shown in Figure 4.3 for the case of the setup cost ,A_S .

Table 4.11
The Effect of Cost Parameters on the Outcome Variables

	As	Ab	rb	rs	Zb	Zs	Cb	Cs	Lb	pr	dr
-50%											
qj	6%	-6%	49%	-3%	-13%	-19%	48%	-3%	-5%	-7%	16%
TRCj	-18%	-7%	-5%	-18%	-1%	-2%	-12%	-18%	-7% .	-23%	7%
Bben	10%	-28%	-29%	7%	3%	5%	-9%	7%	15%	116%	-59%
Sben	92%	-49%	-15%	-37%	33%	-47%	29%	-37%	46%	-69%	30%
-25%											
qj	-3%	0%	18%	0%	-7%	-8%	18%	0%	0%	-3%	10%
TRCj	-8%	-3%	-2%	-8%	-1%	-1%	-5%	-8%	-3%	-6%	4%
Bben	4%	-10%	-11%	3%	2%	3%	-3%	3%	7%	37%	-28%
Sben	30%	-19%	-6%	-14%	10%	-21%	13%	-14%	18%	-13%	17%
25%											
qj	-3%	0%	-13%	-2%	2%	3%	-13%	-2%	1%	-3%	-6%
TRCj	7%	3%	2%	7%	1%	1%	5%	7%	3%	4%	-4%
Bben	-4%	7%	8%	-3%	-2%	-3%	2%	-3%	-6%	-24%	27%
Sben	-24%	13%	2%	8%	-16%	15%	-12%	8%	-19%	7%	-17%
50%											
qj	-3%	0%	-23%	-2%	10%	12%	-19%	-2%	0%	0%	-12%
TRCj	14%	5%	4%	14%	1%	2%	9%	14%	5%	5%	-9%
Bben	-7%	12%	14%	-6%	-3%	-5%	4%	-6%	-11%	-39%	-60%
Sben	-39%	30%	8%	15%	-19%	35%	-20%	15%	-29%	15%	32%

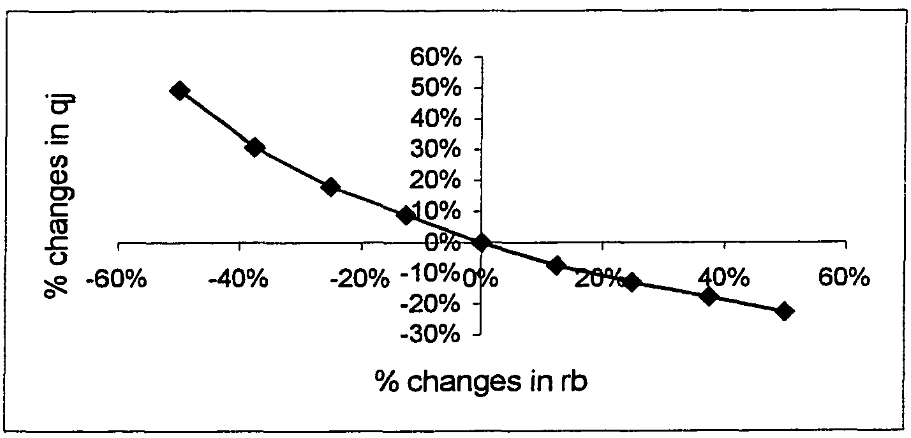

Figure 4.2
The Relationship Between % Change in r_b and % Change in q_j

The percentage change in the total relevant cost can be expressed in the regression equation:

$$TRC_j\% = 0.321\ (A_S\%) - 0.0087 \tag{130}$$

with $R^2 = 0.997$.

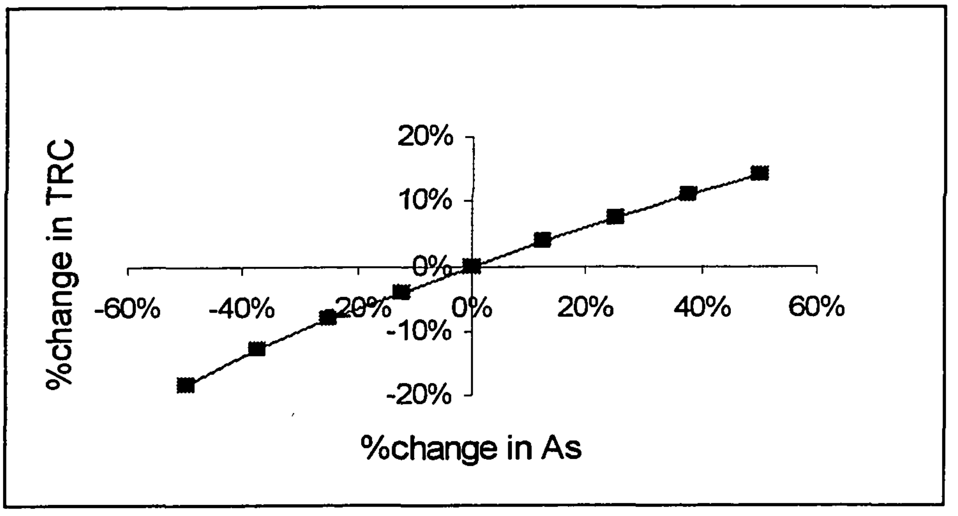

Figure 4.3
The Relationship Between % Change in A_S and % Change in TRC_j

Figure 4.4 illustrates how the changes of production rate p_r and the demand rate d_r will change the buyer's percentage benefits, Bben%. As production rate p_r increases the Bben% is decreases where the change in the demand rate has the opposite effect.

The regression equations are:

$$Bben\% = 1.591\ (p_r\ \%)^2 - 1.42\ (p_r\ \%) - 0.0261 \tag{131}$$

with $R^2 = 0.995$, and

$$Bben\% = 1.1250\ (d_r\ \%) - 0.009 \tag{132}$$

with $R^2 = 0.9997$.

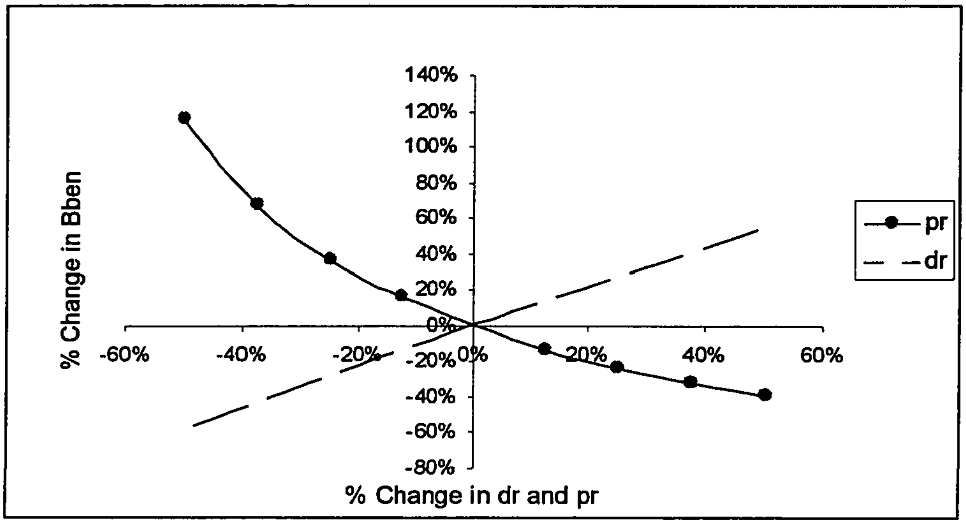

Figure 4.4
The Relationship Between % Change in p_r and d_r with % Change in Bben

In regards to the supplier's benefit, Sben, the ordering cost, shipping cost, and setup cost are the most significant cost parameters affecting the supplier's benefits. As shown in Figure 4.5, the supplier's benefits increase as the ordering cost, A_B, increases. The appropriate regression equations are:

$$\text{Sben}\% = 0.769\,(A_B\%) - 0.0568 \tag{133}$$

with $R^2 = 0.9899$, and

$$\text{Sben}\% = 1.096\,(A_S\%)^2 - 1.227\,(A_S\%) - 0.024 \tag{134}$$

with $R^2 = 0.996$.

4.2.2.1 Sensitivity Analysis for Model 2 Using Two Level Fractional Factorial Designs

In this section, the effects of the parameter changes on the joint optimal solution are investigated. Specifically, we evaluate the effect of the cost parameters and the effect of the production and demand rate on the four most important output characteristics of our Model 2:

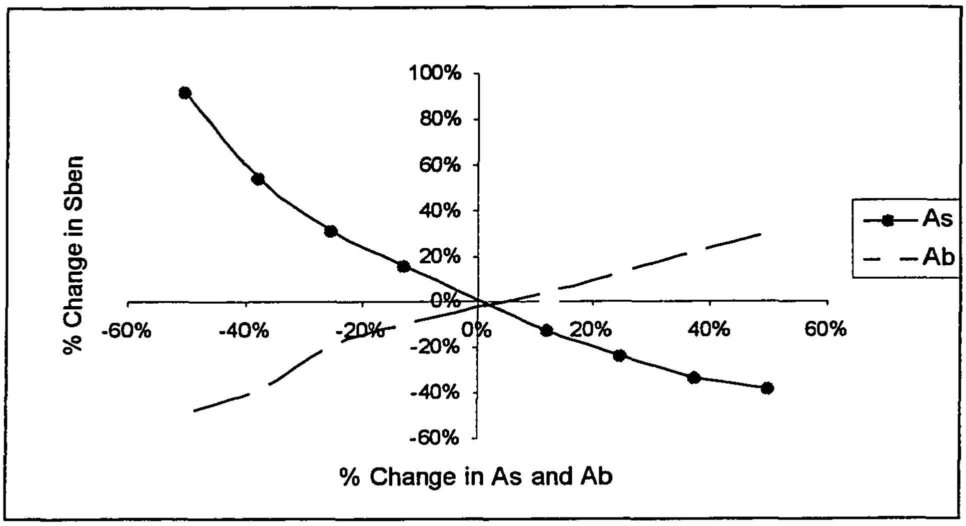

Figure 4.5
The Relationship Between % Change in A_B and A_S with % Change in Sben

- the joint optimal shipment size, $\mathbf{q_J}$,
- the total relevant cost for the joint optimal policy, $\mathbf{TRC_j}$,
- the buyer's benefits, **Bben%**, and
- the supplier's benefit, **Sben%** .

For Model 2 we cannot use the same simple technique that we used in implementing sensitivity analysis for case of no JIT supply (Section 4.2.1.) because we have integer variables and the solution of the model is the result of a numerical solution procedure. We have to apply experimental design. Since the number of the relevant parameters is large (11), it is quite elaborating computational task to run factorial design. We were able to reduce the number of cost parameters to seven and we use two level factorial designs. To reduce the number of experiments we apply

partial factorial design that requires only a fraction of the complete factorial experiment.

For the sake of comparison, we use the same values for the base case as presented in Section 4.1. We modify the base case, for each parameter we use two levels, the increased high level and the decreased low level with the base case in the center. The following variables have been considered as the seven factors in our experiment with the low and high values described next:

(1) A_B/R_B where

A_B is the buyer's ordering cost and $R_B = r_B C_B$ (r_B: buyer's annual carrying cost rate and C_B: the selling price)

(2) Z_B/R_B where

Z_B: the receiving cost for the buyer

(3) L_B/R_B where

L_B: the buyer's cost of losing flexibility as a percentage of selling price

(4) R_S/R_B where

$R_S = r_S C_S$ (r_S: is the suppliers annual inventory carrying cost rate and C_S: is the supplier's production cost)

(5) A_S/A_B where

A_S: is the supplier's setup cost

(6) Z_S/Z_B where

Z_S: is the supplier's cost related to each shipment to buyer

(7) D/P where

D: is the expected annual demand of the product considered

P: is the annual production quantity

For the sake of comparison, we use the same values for the base case as presented in Section 4.1. We modify the base case, for each parameter we use two levels, which are −1 for low value for the parameter and +1 for the high value for the parameter. The table of the high and low levels applied (plus and minus signs) for this experiment is shown in Table 4-12. The high and low value for each factor is presented in Table 4-13

Table 4-12
High and Low Levels (Plus and Minus Signs) for the Experiment

Run	A_B/RB	Z_B/RB	L_B/RB	RS/RB	A_S/A_B	Z_S/Z_B	D/P
1	-1	-1	-1	-1	1	1	1
2	1	-1	-1	1	-1	-1	1
3	-1	1	-1	1	-1	1	-1
4	1	1	-1	-1	1	-1	-1
5	-1	-1	1	1	1	-1	-1
6	1	-1	1	-1	-1	1	-1
7	-1	1	1	-1	-1	-1	1
8	1	1	1	1	1	1	1

Table 4.13
High and Low Value for the Seven Factors

Factor	Low (-1)	High(+1)
A_B/RB	18.75	56
Z_B/RB	0.25	0.75
L_B/RB	0.0025	1.0075
RS/RB	0.04	0.13
A_S/A_B	0.665	2
Z_S/Z_B	0.75	2.25
D/P	0.2	0.6

Once we implement the experiment, we will be able to identify the cost parameters that have the most significant effect on the joint optimal solution. For the base-case parameters, the values for the optimal solution are $q^* = 38$, $TRC^* = 1476$,

and the percent benefits are Bben* = 44% and Sben* = 10%. The experimental results reveal that the ratio between the buyer's ordering cost and inventory holding cost for the buyer, A_B/R_B, and the ratio of shipping and receiving cost for the supplier and the buyer, Z_S/Z_B, are the most influential factors on the joint optimal shipment size, q_j. The two cost factors have almost the identical effect on the shipment size. If we increase either one of them, the shipment size q_j will increase. These results are summarized in Table 4-14.

Table 4.14
Estimates of Effects on the Joint Optimal Shipment Size, q_j,

Run	q_j	A_B/RB	Z_B/RB	L_B/RB	RS/RB	A_S/A_B	Z_S/Z_B	D/P
1	38	-38	-38	-38	-38	38	38	38
2	46	46	-46	-46	46	-46	-46	46
3	47	-47	47	-47	47	-47	47	-47
4	40	40	40	-40	-40	40	-40	-40
5	26	-26	-26	26	26	26	-26	-26
6	46	46	-46	46	-46	-46	46	-46
7	41	-41	41	41	-41	-41	-41	41
8	81	81	81	81	81	81	81	81
Total		60	53	23	35	4	58	47
Total/4		15	13	6	9	1	15	12

Also, we find that the ratio between the setup cost for the supplier and the ordering cost for the buyer, A_S/A_B, and ratio of inventory holding cost of the supplier and inventory holding cost for the buyer, R_S/R_B, are causing the highest positive changes in the joint optimal value of the total relevant cost, TRC_j. This is illustrated in Table 4-15.

Next the effect of parameter changes on the cost savings achieved by using the joint optimal policy are investigated. The buyer's benefits, **Bben%**, expresses the

Table 4.15
Estimates of Effects on the Total Relevant Cost for the Joint Optimal Policy, TRC_j,

Run	TRC_j	A_B/RB	Z_B/RB	L_B/RB	RS/RB	A_S/A_B	Z_S/Z_B	D/P
1	1295	-1295	-1295	-1295	-1295	1295	1295	1295
2	1287	1287	-1287	-1287	1287	-1287	-1287	1287
3	1098	-1098	1098	-1098	1098	-1098	1098	-1098
4	1148	1148	1148	-1148	-1148	1148	-1148	-1148
5	1580	-1580	-1580	1580	1580	1580	-1580	-1580
6	1113	1113	-1113	1113	-1113	-1113	1113	-1113
7	1001	-1001	1001	1001	-1001	-1001	-1001	1001
8	2231	2231	2231	2231	2231	2231	2231	2231
Total		805	203	1097	1640	1755	720	875
Total/4		201	51	274	410	439	180	219

percentage cost improvement achieved by the buyer (after compensating the supplier's loss) by switching from the supplier's optimal policy to the joint optimal policy. Similarly, the supplier's benefit, **Sben%**, expresses the supplier's percent cost improvement by switching form the buyer's optimal policy to the joint optimum. Table 4-16 shows that how the changes in the ratio of inventory holding cost for both supplier and buyer, R_S/R_B, have the largest positive effect on the buyer's benefits, Bben%. On the other hand, the ratio between the buyer's demand rate and the supplier's production rate, D/P, has the largest negative effect on the buyer's benefits, Bben%.

In regards to the supplier's benefit, Sben%, the results reveal that the ratio between the buyer's ordering cost and inventory holding cost for the buyer, A_B/R_B, have the largest positive effect. In contrast, we find that the ratio between the setup cost for the supplier and the ordering cost for the buyer, A_S/A_B, have the largest negative effect on the supplier's benefits. These results describe in Table 4-17.

Table 4.16
Estimates of Effects on the Buyer's Benefits, Bben%,

Run	Bben%	A_B/RB	Z_B/RB	L_B/RB	RS/RB	A_S/A_B	Z_S/Z_B	D/P
1	-4%	4%	4%	4%	4%	-4%	-4%	-4%
2	40%	40%	-40%	-40%	40%	-40%	-40%	40%
3	64%	-64%	64%	-64%	64%	-64%	64%	-64%
4	74%	74%	74%	-74%	-74%	74%	-74%	-74%
5	75%	-75%	-75%	75%	75%	75%	-75%	-75%
6	55%	55%	-55%	55%	-55%	-55%	55%	-55%
7	13%	-13%	13%	13%	-13%	-13%	-13%	13%
8	1%	1%	1%	1%	1%	1%	1%	1%
Total		22%	-13%	-30%	41%	-27%	-87%	-219%
Total/4		6%	-3%	-7%	10%	-7%	-22%	-55%

Table 4-17
Estimates of Effects on the Supplier's Benefit, Sben%

Run	Sben%	A_B/RB	Z_B/RB	L_B/RB	RS/RB	A_S/A_B	Z_S/Z_B	D/P
1	10%	-10%	-10%	-10%	-10%	10%	10%	10%
2	30%	30%	-30%	-30%	30%	-30%	-30%	30%
3	16%	-16%	16%	-16%	16%	-16%	16%	-16%
4	3%	3%	3%	-3%	-3%	3%	-3%	-3%
5	0%	0%	0%	0%	0%	0%	0%	0%
6	19%	19%	-19%	19%	-19%	-19%	19%	-19%
7	3%	-3%	3%	3%	-3%	-3%	-3%	3%
8	13%	13%	13%	13%	13%	13%	13%	13%
Total		36%	-24%	-24%	25%	-43%	23%	17%
Total/4		9%	-6%	-6%	6%	-11%	6%	4%

4.3 Numerical and Managerial Analysis for the Case of Uncertainty

One of the major assumptions under JIT supply is that the buyer and supplier operate in a deterministic environment and neither the buyer nor the supplier has to hold safety stock. However, in most practical cases, this assumption is not realistic. There are two options to maintain the required service level and to reduce uncertainty. The first option is that the supplier has flexible resources and the short production and supply lead-time enables to maintain the required service level without keeping safety stock. This option may not always feasible, especially in a short term, because of the high investment in flexible technology, machines, and workers. The other option is that either the supplier or buyer holds a safety stock to protect against uncertainty. In this case, however considerable additional holding cost may occur.

The first section will focus on the effect of increasing demand uncertainty on the producer's costs. It provides a sense of how economic or costly it is to invest in flexible resources. Next we will address the second option, where the buyer or the supplier has to hold safety stock.

4.3.1 The Effect of Demand Uncertainty on the Production Costs

First, we examine the effect of increasing demand uncertainty on the cost of the producer based on the model described in Section (3.3.1). We decrease the rate of the fixed contracted annual demand, D_C, relative to the random part of the annual demand, D_R. In our numerical example, D_C is decreased from 300 to 100 while the expected value of the random demand, μ is fixed as 50. The annual production capacity of dedicated production resources level, $R_d = D_C + \mu$. The annual production

capacity of the flexible production resources is chosen to be large enough to satisfy the demand with a high service level. For the flexible resource $R_f = k\sigma$, where we choose k=2 and k= 1.67 that correspond to a service level of 97.72% and 90% , respectively. Also for comparison, we choose to have the same total resource level, R_d+R_f, so the resulting σ values vary between 100 and 0. For larger D_c values, σ is smaller.

The numerical results revealed the following tendencies. The unit cost of production and unused resources increases with the increase of demand uncertainty, as we expect. The marginal cost increase is not linear. An increasing marginal cost is observed as it is illustrated on Table.4.18 and Figure 4.6 As long as the σ/μ rate (coefficient of variation) is less than 1, the cost increase is within 10% range, but for $\sigma/\mu = 2$, the cost increase can be in the area of 200%. The cost increase is influenced by the cost rates v_f/v_d and u/v_d (where v_d denotes the unit production cost with dedicated resources, v_f denotes the unit production cost with flexible resources and u denotes the unit cost of unused dedicated production resources). The effect of the cost rate u/v_d seems to be larger based on the numerical results. Moreover, for lower service level (as k decreases), the cost saving will be larger as it illustrated on Table.4.19. and Figure 4.7. These quantitative results show that in the case of high demand uncertainty and high cost of unused capacity, a particularly large cost increase can be expected with the increase of demand uncertainty. Appendix B contains further illustration.

The above model provides a quantitative tool to evaluate the option of investing in flexible resources or rather rely on safety stocks. Certainly, the

production costs are only one of the factors considered in the decision, still quantifying them provides a major decision support in the above decision.

4.3.2 Error Analysis and Correction of the Safety Stock Approximation

In the next two sections, we summarize our numerical results of error analysis and correction of safety stock approximations. First, we discuss the situation when the buyer is responsible for the safety stock. Then, we discuss the case when the supplier takes the responsibility of holding safety stock.

4.3.2.1 The Case When the Buyer Holds the Safety Stock

In Section 3.2.2.2, we introduced the model published in Kelle and Miller (1998) for the case when the JIT supply is not reliable and the buyer needs to hold safety stock. For a given safety stock, M, expression (45) gives the (exact) service level, which we denote by α_e, while formula (51) provides a simple approximation, we denote by α_a. It is known that the approximation, α_a, is quite inaccurate for a small number of shipments, n, since it is based on an asymptotic relation which is true as n goes to infinity. Since the relative error is high even for moderately large n, we provide a simple correction formula based on a regression model to minimize the error. Corrections of this approximation were not considered in the literature before.

If the target service level is given, the required safety stock, M_e, can be calculated by using numerical methods, based on expression (45). Using the simple approximation (51), the required safety stock can be approximated by the simple formula (51), which also has a high relative error. Here, we also provide a correction formula based on a regression model.

Table 4.18
Effect of Decreasing Demand Uncertainty on the Unit Production Cost

D_C=	100	120	140	160	180	200	220	240	260	280	300
$D_R=\mu+k^*\sigma=$	250	230	210	190	170	150	130	110	90	70	50
$R_d=D_C+\mu=$	150	170	190	210	230	250	270	290	310	330	350
$R_f=k^*\sigma=$	200	180	160	140	120	100	80	60	40	20	0
	Rate of increase in expected unit production cost, V:										
Cost rates σ =	100	90	80	70	60	50	40	30	20	10	0
v_f/v_d=1.2 u/v_d=0.2	1.33	1.22	1.13	1.07	1.05	1.03	1.02	1.02	1.01	1.01	1.00
v_f/v_d=1.2, u/v_d=0.4	1.63	1.41	1.23	1.12	1.07	1.05	1.03	1.02	1.01	1.01	1.00
v_f/v_d=1.2, u/v_d=0.6	1.93	1.60	1.34	1.17	1.10	1.07	1.04	1.03	1.02	1.01	1.00
v_f/v_d=1.5 u/v_d=0.2	1.38	1.27	1.17	1.11	1.07	1.06	1.04	1.03	1.02	1.01	1.00
v_f/v_d=1.5, u/v_d=0.4	1.68	1.46	1.27	1.16	1.10	1.07	1.05	1.04	1.02	1.01	1.00
v_f/v_d=1.5, u/v_d=0.6	1.98	1.65	1.37	1.21	1.13	1.09	1.06	1.04	1.03	1.02	1.00

K=2, $R_d + R_f$=350

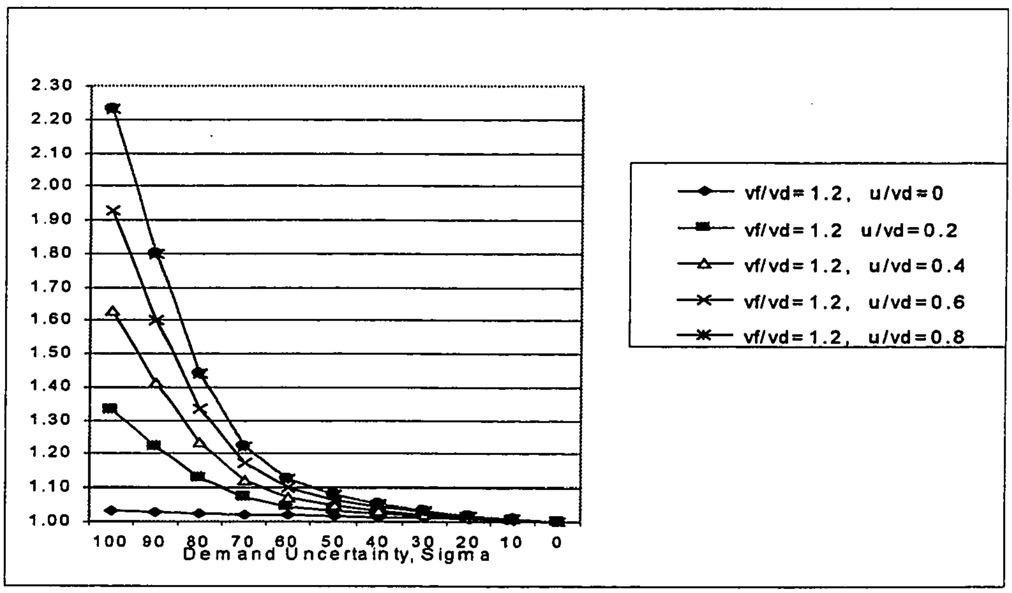

Figure 4.6
Rate of Increase in Expected Unit Production Cost, V:
Service Level = 97.5%

Table 4.19
Effect of Decreasing Demand Uncertainty on the Unit Production Cost

D_C=	100	120	140	160	180	200	220	240	260	280	300
$D_R=\mu+k*\sigma$=	215	199	182	166	149	133	116	99.5	83	66.5	50
$R_d=D_C+\mu$=	150	170	190	210	230	250	270	290	310	330	350
$R_f=k*\sigma$=	165	149	132	116	99	82.5	66	49.5	33	16.5	0
			Rate of increase in expected unit production cost, V:								
Cost rates σ =	100	90	80	70	60	50	40	30	20	10	0
v_f/v_d=1.2, u/v_d=0	1.04	1.03	1.03	1.02	1.02	1.02	1.01	1.01	1.01	1.01	1.00
v_f/v_d=1.2 u/v_d=0.2	1.46	1.34	1.22	1.12	1.06	1.04	1.03	1.02	1.01	1.01	1.00
v_f/v_d=1.2, u/v_d=0.4	1.88	1.64	1.40	1.21	1.11	1.06	1.04	1.03	1.02	1.01	1.00
v_f/v_d=1.2, u/v_d=0.6	2.30	1.95	1.59	1.31	1.15	1.09	1.06	1.04	1.02	1.01	1.00
v_f/v_d=1.2, u/v_d=0.8	2.72	2.26	1.78	1.40	1.20	1.11	1.07	1.04	1.02	1.01	1.00

K=2, $R_d + R_f$ =350

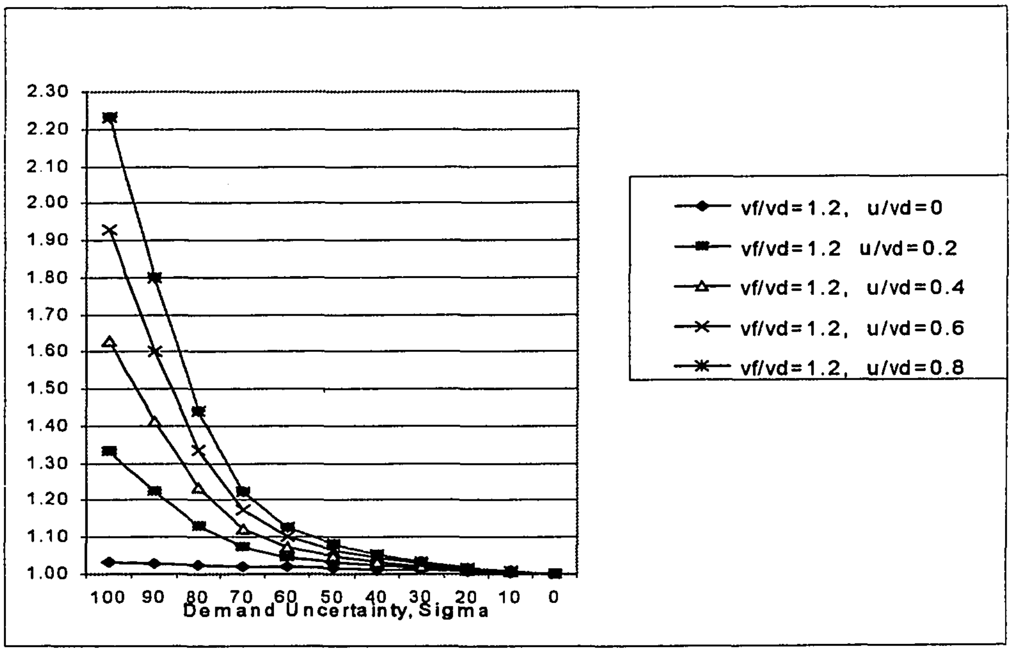

Figure 4.7
Rate of Increase in Expected Unit Production Cost, V:
Service Level = 90%

First, we consider the relative error of approximation α_a, based on formula (51) by using different M and n values. The numerical results reveal that by increasing M, the relative error of α_a decreases. For larger n, small changes in M do not have much influence on the relative error. An illustration is shown in Table 4.20 and in Figure 4.8. Further results for different values of M and n are presented in Appendix B.

Table 4.20
Relative Error in the Approximation of Alpha for n=10

M/n	10	10	10
	exact	Approx.	error
0.15	0.417	0.362	-13.1%
0.2	0.603	0.551	-8.7%
0.25	0.755	0.713	-5.5%
0.30	0.865	0.835	-3.5%
0.35	0.933	0.914	-2.1%
0.40	0.971	0.959	-1.2%
0.45	0.989	0.983	-0.6%
0.50	0.996	0.993	-0.3%

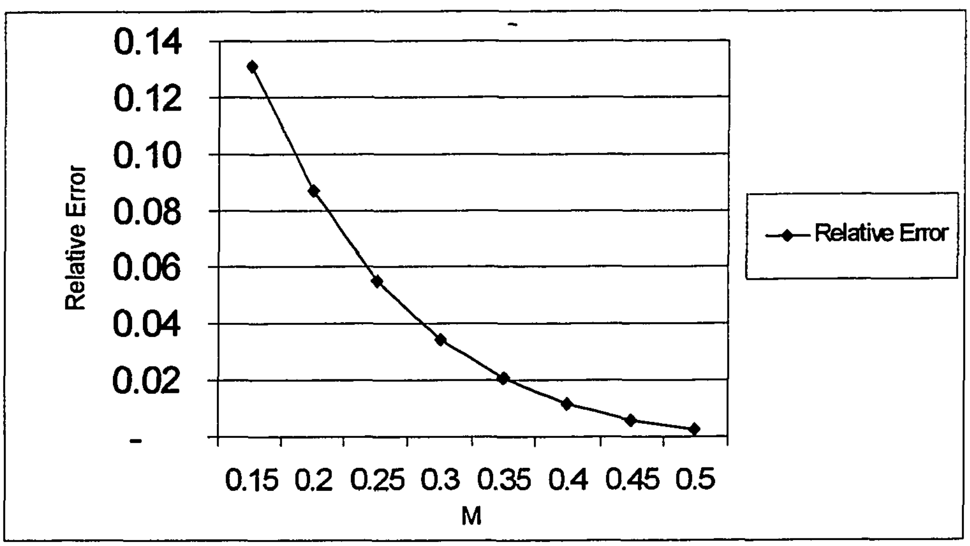

Figure 4.8
Relative Error in the Approximation of α for n=10

The speed of the convergence of the asymptotic expression (42) is quite slow as it is shown in Table 4.21 and Figure 4.9. In general, the smaller the values of M, n, and α, the larger the relative error of α_a (see Table 4.22, Figure 4.10, and Figure 4.11)

Table 4.21
Relative Error in α for Different n Values

M/n	10	15	20	25	30	35	40	45	50
0.15	-13.1%	-8.4%	-5.8%	-4.2%	-3.1%	-2.4%	-1.8%	-1.3%	-1.1%
0.2	-8.7%	-4.9%	-3.0%	-1.9%	-1.3%	-0.8%	-0.6%	-0.4%	-0.3%
0.25	-5.5%	-2.7%	-1.4%	-0.8%	-0.4%	-0.2%	-0.1%	-	-
0.3	-3.5%	-1.4%	-0.6%	-0.3%	-0.1%	-	-	-	-
0.35	-2.1%	-0.6%	-0.2%	-	-	-	-	-	-
0.4	-1.2%	-0.3%	-	-	-	-	-	-	-
0.45	-0.6%	-	-	-	-	-	-	-	-
0.5	-0.3%	-	-	-	-	-	-	-	-

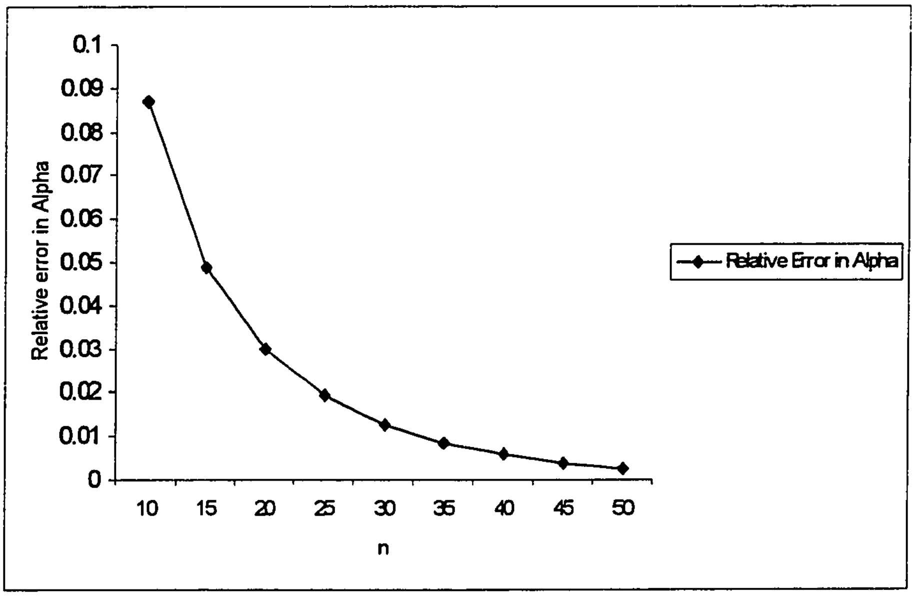

Figure 4.9
Relative Error in α for M=0.2

Table 4.22
Relative Error in Alpha for Different n and α Values

α/n	10	15	20	25	30	35	40	45	50
0.8	-4.62%	-3.98%	-3.32%	-2.97%	-2.72%	-2.52%	-2.36%	-2.23%	-2.12%
0.85	-3.81%	-3.04%	-2.61%	-2.33%	-2.14%	-1.98%	-1.84%	-1.74%	-1.65%
0.9	-2.82%	-2.19%	-1.95%	-1.63%	-1.54%	-1.42%	-1.23%	-1.26%	-1.18%
0.95	-1.66%	-1.40%	-1.21%	-0.94%	-0.89%	-0.85%	-0.68%	-0.72%	-0.67%

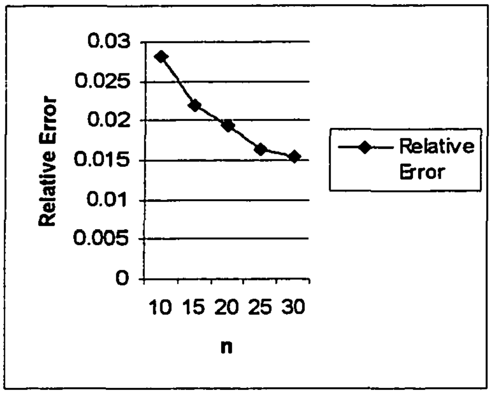

Figure 4.10
Relative Error in α, for Alpha = 0.9

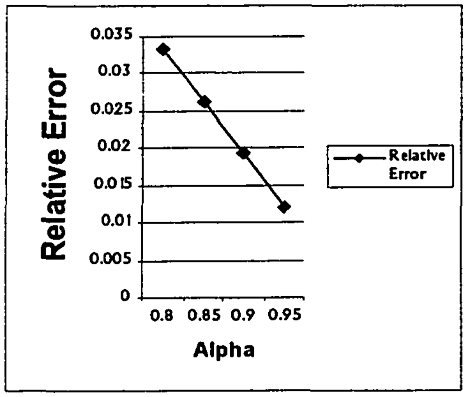

Figure 4.11
Relative Error in α, for Alpha = 0.9

The exact expression (38) requires tedious computation. The large error of the simple approximation makes it important to use some type of correction. We use regression analysis. In order to minimize the relative error in α, we used the Least Square Method (LSM) and developed the following correction formula:

Corrected (α) = 0.1442 + Approximate (α) – 0.0653 (Log (n)) – 0.1685 (M) (113)

The range of relative error between the predicted value of α and the exact value of α is between 0% and 1.1%. An illustration is shown in Figure 4.12.

Next, we analyze the relative error in the approximation (43) of the required safety stock by using different values of α and n. Our numerical results reveal that with the decrease of α, the relative error in safety stock increases. These effects are

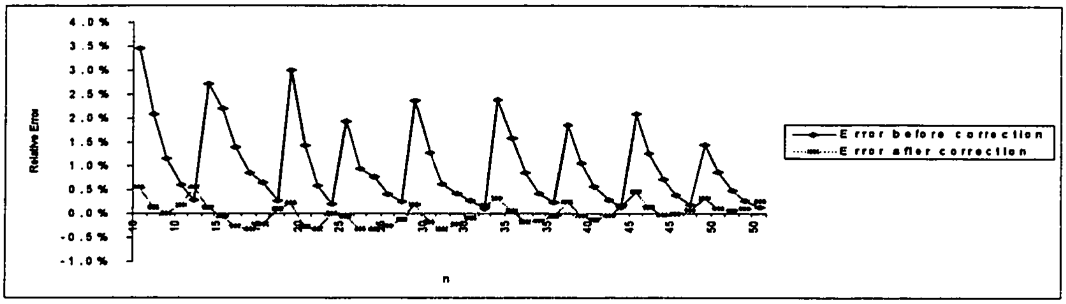

Figure 4.12
Comparison of Relative Error in α

illustrated in Table 4.23 and Figure 4.13.

Table 4.23
Relative Error of Safety Stock Estimation, Ma (for n=20)

α/n	20	20	20
	Me	Ma	Me-Ma/Me
0.8	0.193	0.200	-4.0%
0.85	0.210	0.217	-3.7%
0.9	0.231	0.240	-3.5%
0.95	0.264	0.273	-3.4%

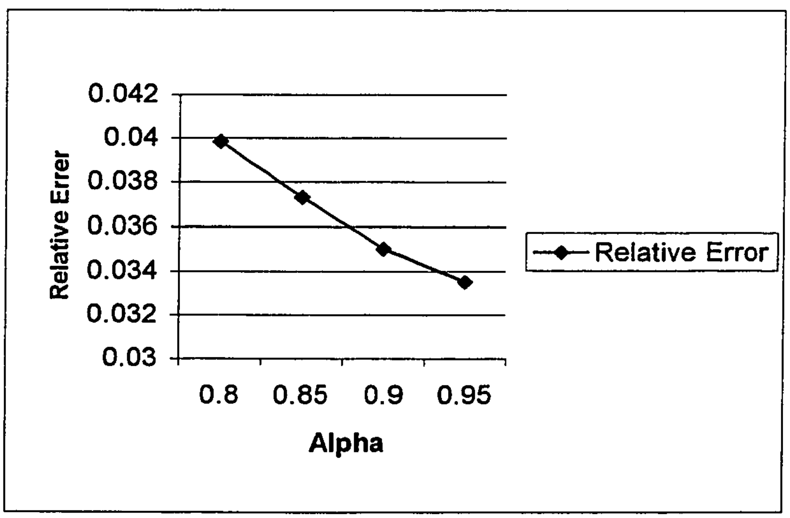

Figure 4.13
Relative Error of Safety Stock Estimation, Ma (for n=20)

Since the approximation is based on asymptotic results (when n goes to infinity), the relative error in safety stock approximation decreases as the value of n increases. An illustration of this tendency is shown in Table 4.24 and in Figure 4.14.

Table 4.24
Relative Error in Safety Stock for Different m and α Values

n=	5	10	15	20	25	30	35	40	45	50	55
alpha											
0.8	-8.4%	-5.8%	-4.8%	-4.0%	-3.6%	-3.3%	-3.0%	-2.7%	-2.7%	-2.5%	-2.4%
0.85	-7.9%	-5.5%	-4.6%	-3.7%	-3.5%	-3.1%	-2.9%	-2.7%	-2.5%	-2.4%	-2.3%
0.9	-7.4%	-5.2%	-4.0%	-3.5%	-3.3%	-2.9%	-2.7%	-2.5%	-2.3%	-2.3%	-2.2%
0.95	-7.3%	-5.1%	-3.9%	-3.4%	-2.9%	-2.6%	-2.4%	-2.3%	-2.2%	-2.0%	-1.9%

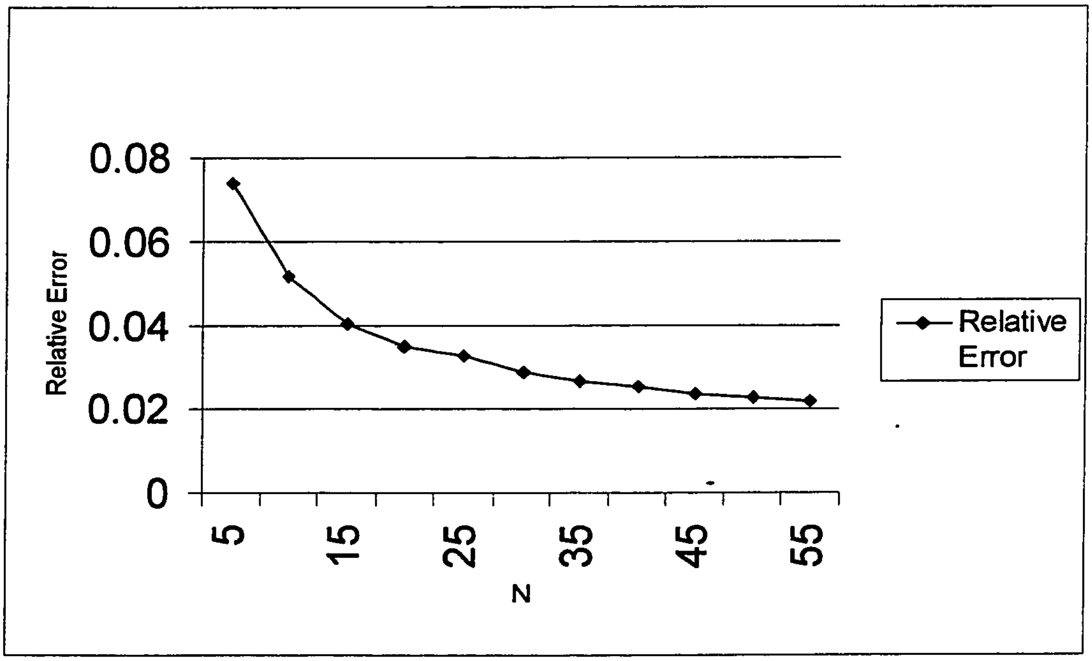

Figure 4.14
Relative Error in Safety Stock, Ma, for Alpha =0.8

Since the exact value of the safety stock, M_e, can only be calculated with a numerical search procedure based on expression (38), it is critical for the application to have a simple approximation. The large error of the simple approximation, M_a,

makes it important to use some kind of correction. We use regression analysis. In order to minimize the relative error, we used the Least Square Method (LSM) and developed the following correction formula:

$$\text{Corrected (M)} = Me - 0.02803 + 0.0184(\text{Log}(n)) - 0.0061(\alpha) \qquad (135)$$

The range of relative error between the corrected safety stock and exact safety stock is between 0% and 3% as is illustrated in Figure 4.15. The new regression function in (135) can provide a good approximation .

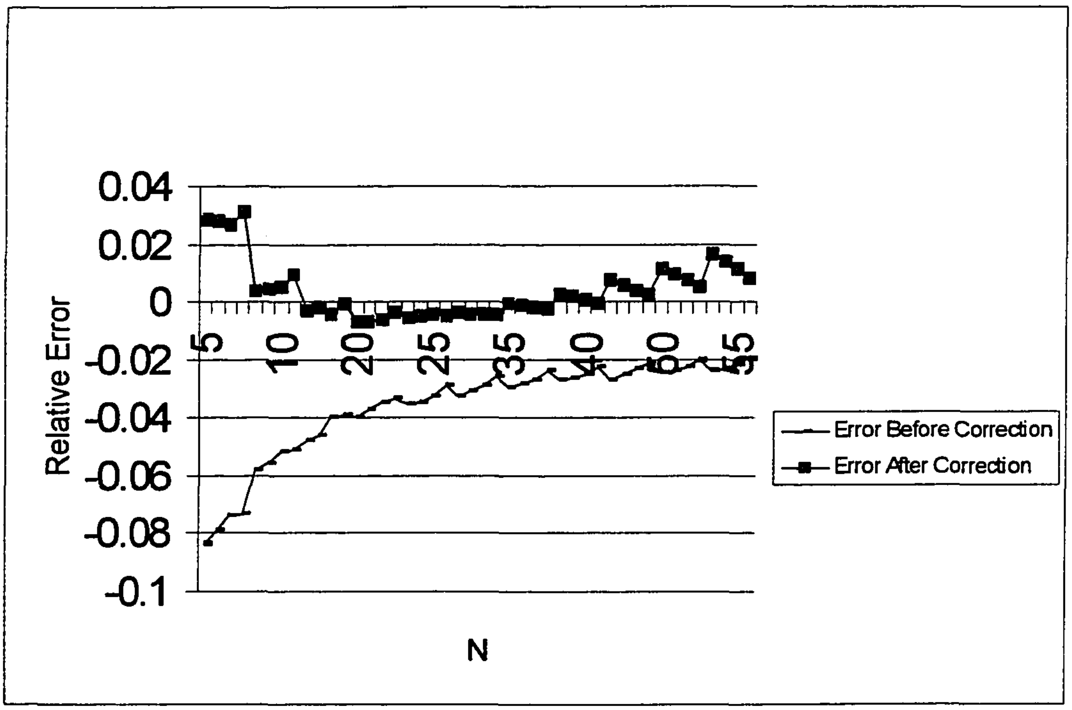

Figure 4.15
Relative Error in Ma and in Corrected M

4.3.2.2 The Case When the Supplier Holds the Safety Stock

This section considers the case when the supplier is responsible for keeping a safety stock of finished goods to meet the buyer's shipment request on time, according to the JIT delivery agreement. In Section 3.3.3, we introduced a new model for the safety stock requirements of the supplier if the supplier's capacity is not flexible enough to meet the buyer's request without holding safety stocks. For a given safety stock, M, expression (72) gives the (exact) service level, we denote by α_e, while formula (74) provides a simple approximation, which we denote by α_a. The service level depends on the number of shipments of an order, denoted by n, and also on the number of setups per customer order, denoted by k. First, we check the accuracy of this approximation (74), which is based on an asymptotic relation that holds as both n and k go to infinity.

If the target service level is given, we want to find the required safety stock. The exact value of the safety stock, denoted by M_e, can be calculated by numerical methods, based on expression (72). Using the asymptotic relation (74), the required safety stock can be approximated with the simple formula (75). We compare the exact value of the safety stock with the approximation, M_a.

First, we consider the relative error in α by using different values of M, n, and k. The numerical results reveal that if we increase M, the relative error in α decreases. For larger n, or k values, small changes in M do not have much influence on the relative error. An illustration is shown in Table 4.25 and Figure 4.16. The effect of changing the parameter k is also interesting. The relative error in α

decreases as k increases assuming other parameters remain unchanged as it is shown in Figure 4.17.

Table 4.25
Relative Error in the Approximation of ,α

k=1

M/n	10	20	30	40	50
0.1	-70.1%	-49.1%	-36.6%	-28.6%	-22.9%
0.2	-43.2%	-22.2%	-12.9%	-7.9%	-5.1%
0.3	-24.9%	-8.5%	-3.3%	-1.3%	-0.5%
0.4	-12.9%	-2.4%	-0.5%	-0.1%	
0.5	-5.7%	-0.5%			
0.6	-2.1%	-0.1%			
0.7	-0.6%				

k=2

M/n	10	20	30	40	50
0.1	-73.4%	-55.4%	-42.0%	-34.1%	-28.0%
0.2	-50.8%	-28.9%	-18.5%	-12.6%	-8.9%
0.3	-32.0%	-14.3%	-7.1%	-3.7%	-2.0%
0.4	-20.5%	-6.1%	-2.1%	-0.7%	-0.3%
0.5	-11.6%	-2.1%	-0.4%	-0.1%	
0.6	-6.2%	-0.6%	-0.1%		
0.7	-2.9%	-0.1%			
0.8	-1.2%				

k=3

M/n	30	60	90	120
0.1	-47.7%	-27.5%	-18.5%	-13.4%
0.2	-22.9%	-9.3%	-4.5%	-2.3%
0.3	-10.5%	-2.3%	-0.6%	-0.2%
0.4	-4.5%	-0.4%		
0.5	-1.4%			
0.6	-0.3%			

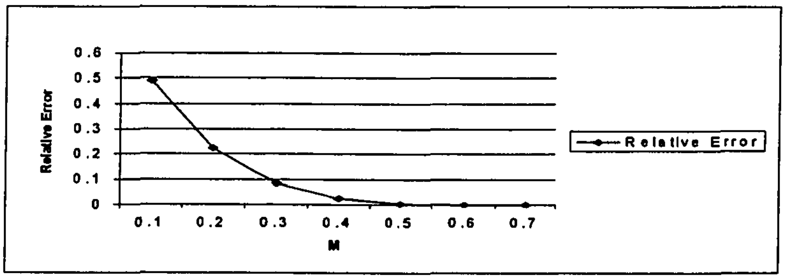

Figure 4.16
Relative Error in ,α, for n=20

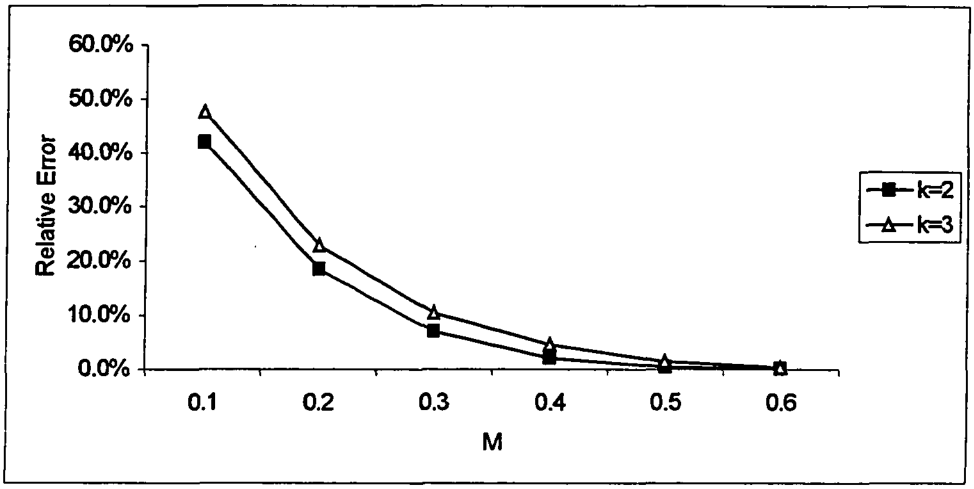

Figure 4.17
Relative Error in ,α, for k=2, k=3 and n=30

For the supplier safety stock model we cannot develop a regression model for correcting the error of the service level approximation, like we did in the previous section for the buyer's case, because the service level, α is a step function of M. There are jumps at the values of c/n, where c is an integer ($1 \le c \le n$). However, the approximation is quite accurate also for relatively small k and n values at the jumps as it is shown in Figure 4.18.The error is less than 1% if the α value is larger than 0.8, which is the case in practice for the required service level, α. Thus, we can use the simple approximation for α in the practically important cases.

Next, we analyze the relative error of the safety stock expression (75) by using different values of α, n and k. The numerical results reveal that as we increase k, the relative error in safety stock decreases as shown in Figure 4.19. In regards to changes in α and n, there is no specific trend. These scenarios are described in Table 4.26, Figure 4.20, and Figure 4.21.

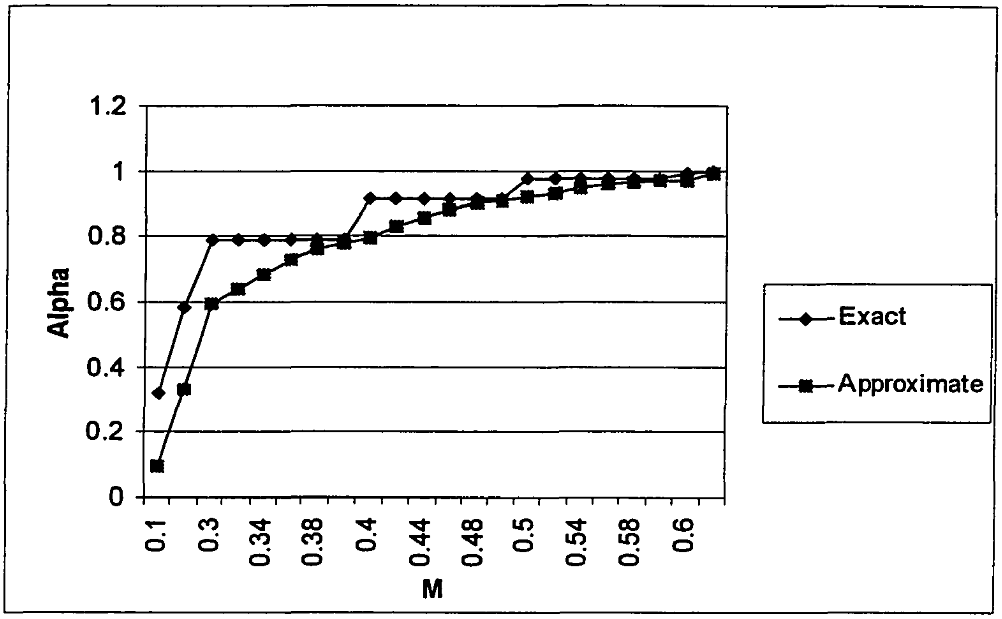

Figure 4.18
Exact Value and. Approximation of ,α, for n=k=10

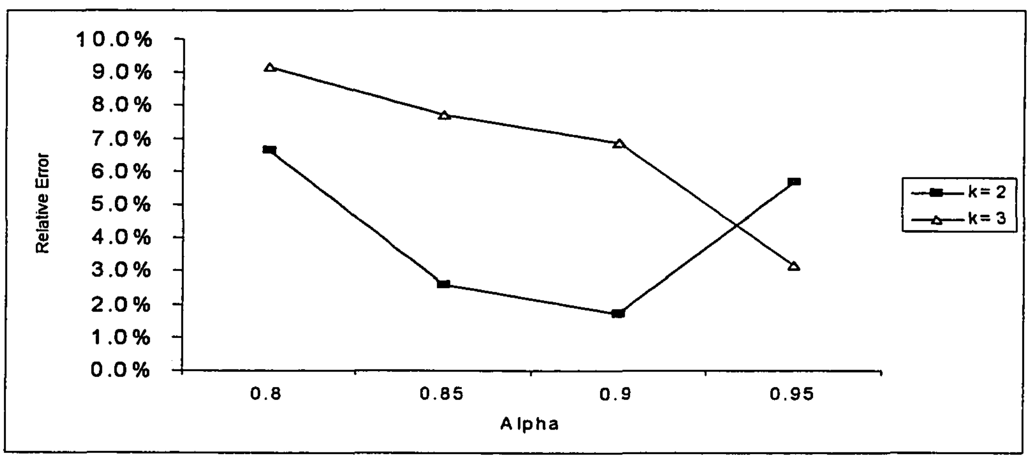

Figure 4.19
Relative Error in Safety Stock for k=2, k=3, and n=30

Table 4.26
Relative Error in Safety Stock

k=1

α/n	10	20	30	40	50
0.8	0.2%	13.6%	15.9%	0.2%	12.0%
0.85	8.8%	2.6%	7.7%	8.8%	8.2%
0.9	19.8%	12.9%	3.8%	6.5%	7.3%
0.95	9.4%	10.5%	5.3%	9.4%	2.0%

k=2

α/n	10	20	30	40	50
0.8	22.8%	15.9%	6.6%	9.2%	9.9%
0.85	6.6%	7.7%	2.6%	6.6%	8.4%
0.9	17.4%	3.7%	1.7%	6.7%	9.3%
0.95	11.7%	5.3%	5.7%	3.1%	7.0%

k=3

α/n	30	60	90	120
0.8	9.2%	7.2%	6.8%	3.7%
0.85	7.7%	7.9%	2.6%	1.5%
0.9	6.9%	4.0%	1.7%	2.4%
0.95	3.2%	5.3%	5.5%	3.1%

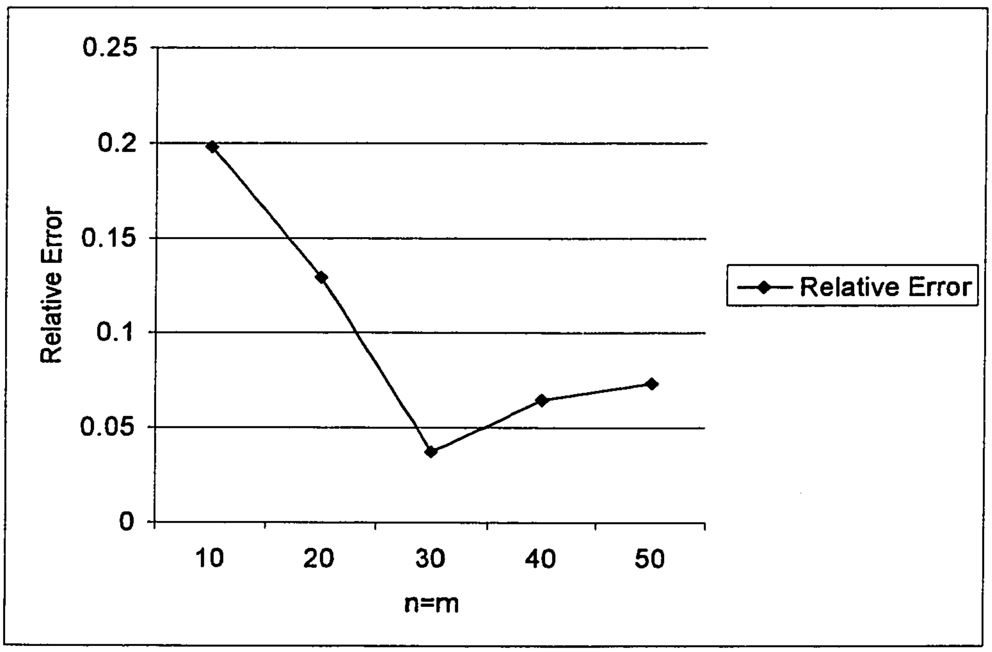

Figure 4.20
Relative Error in Safety Stock when n=k=30

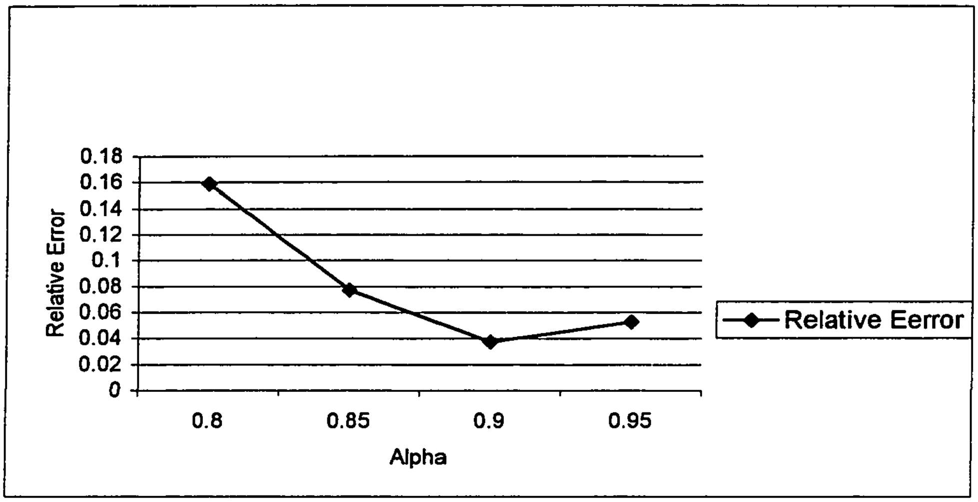

Figure 4.21
Relative Error in Safety Stock when ,$\alpha = 0.9$

Similar to the service level approximation of the supplier's case, we cannot develop a regression model for correcting the error of the safety stock approximation (75), because the safety stock, M, is a step function of α. There are jumps at the values of $M = c/n$, where c is an integer ($1 \leq c \leq n$). However, the approximation is quite accurate also for relatively small k and n values in at the jumps as it is shown in Figure 4.22. The error is less than 1% if the α value is larger than 0.8, which is the case for the required service level, α. Thus, we can use the simple approximation for α in the practically important cases. If the safety stock $M=c/n$ is used with integer c values, this is equivalent to holding integer multiple of shipments size as a safety stock.

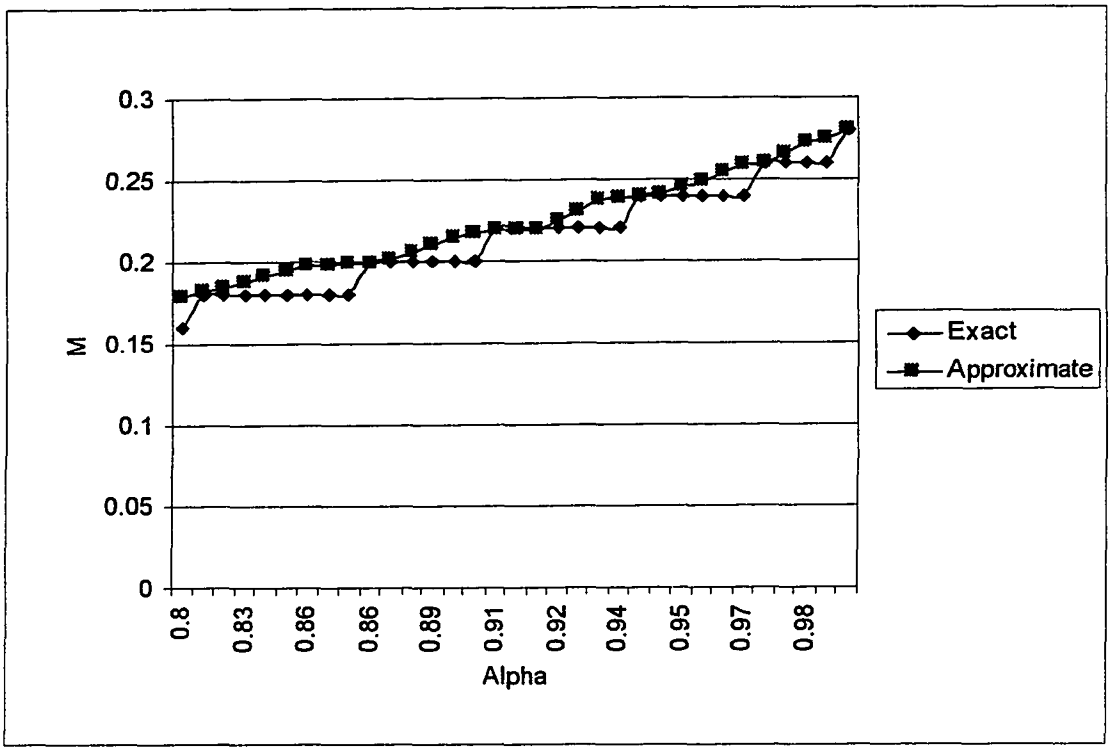

Figure 4.22
Exact Safety Stock and Approximate Safety Stock
when n=50 and k=50

4.3.3 Numerical and Managerial Analysis When the Buyer is Holding Safety Stock (Model 3)

In Section 3.4.3, we introduced Model 3 for the case when the JIT delivery is not reliable and the buyer needs to hold safety stock. In this section, first, we provide the numerical solution for the base-case set of parameters introduced in Section 4.1 and used previously also in the other models for comparing the different scenarios. Next, we give a sensitivity and managerial analysis of Model 3.

If the buyer is strong, we can find the optimal values for the shipment size, q, and the number of shipments, n, respectively using expression (114) and expression (115). The optimal number of shipments for the buyer is n=26 and the optimal

shipment size, q, is 14. The numerical and cost results are summarized in the first column of Table 4.27. The buyer's total cost is \$ 1100 and using the buyer's optimal the supplier total cost is \$ 1137.

Table 4.27
Optimal Ordering Policies and Relevant Costs

Policy	Buyer's Optimal	Supplier's Optimal	Joint optimal
K	-	-	1
Number of shipment per order n	26	-	26
Number of shipment per lot size m	-	26	26
Shipment size q	14	20	17
Order quantity Q_B	364	-	442
Production lot size Q_S	-	520	442
Buyer's TRC	1100	1165	1116
Supplier's TRC	1137	1073	1089
Overall TRCJ	2237	2238	2205
Buyer's Loss	0.00	6%	1%
Supplier's loss	6%	0.00	2%

Similarly, if the supplier is strong, then the supplier can chose its best lot size as an integer multiple of the shipment quantity, $Q_S = mq_B$. The numerical and cost results are summarized in the second column of Table 4.5. It shows the optimal shipment size for the supplier is 20 and the supplier's total cost is \$ 1073. If the buyer must accept the optimal lot size of the supplier, $Q_S = q_S$ as the shipment size, the buyer's total cost is \$ 1165.

For the joint optimal policy of the two parties, we use the results of Section 3.4.3. From expression (99), we find the optimal values for the shipment size, q, and the value of n, and m, respectively, using an iterative calculation. The optimal value of n and m is the same, 26. The optimal shipment size $q_J^* = 17$. If the two parties

accept the joint shipment size, the total costs for the buyer is $TRC_B(q_J^*)$ = \$ 1116, for the supplier, $TRC_S(q_J^*)$ = \$ 1089, and the total system cost is the minimum, \$ 2205. Thus, the total system cost can be decreased by \$ 32 (2%) if the two parties are ready to switch from the buyer's optimal policy to the joint optimal policy. Similarly, the total system gain is \$ 33 (2%) by switching from the supplier's optimal policy to the joint optimal policy.

As in the previous section, we examine the three different scenarios in *negotiation, now considering the JIT supply case.*

a.) If the **supplier is strong**, the buyer is willing to negotiate with the supplier for acceptance of the joint order quantity in order to minimize the loss that is incurred by using the supplier's optimal lot size as the shipment quantity. The buyer could have a cost decrease up to \$ 16 (3%) after compensating the supplier for its loss. The costs are summarized in Table 4.28.

Table 4.28
Moving from Supplier's Optimal to Joint Optimal

	Buyer's Cost	Supplier Cost	Total Cost
Supplier Optimal	1165	1073	2238
Joint Optimal	1116	1089	2205
Cost Improvement	50	-16	34
Compensation	-16	16	0
Buyer Benefit	34	0	34
Bben%	3%	-	-

b.) Similarly, we examine the case where the **buyer is stronger** than the supplier. In this case, the supplier is willing to make some sort of concession, such as price discount, to the buyer to encourage the latter to accept the joint order

quantity. The supplier could have a cost decrease up to \$ 16 (3%) after compensating the buyer for its loss. Table 4.29 summarizes this result.

Table 4.29
Moving from Buyer's Optimal to Joint Optimal

	Buyer's Cost	Supplier Cost	Total Cost
Supplier Optimal	1100	1137	2237
Joint Optimal	1116	1089	2205
Cost Improvement	-16	48	32
Compensation	16	-16	0
Supplier Benefit	0	32	32
Sben%	-	3%	-

c.) If the **buyer and supplier are willing to coordinate**, and adjust their policy to the optimal joint shipment size, only a very small gain (2%) can be achieved relative to the buyer's optimal policy in this numerical example. We will explore this issue later in more detail considering several different parameters.

Similarly, as in Section 4.2.2, we evaluate the effect of the cost parameters on the joint optimal solution. We use the cost information from the previous example with the base-case parameter values used in each comparison. The values for the optimal solution are $q^* = 17$, $TRC^* = 2205$, $Bben^* = 3\%$ and $Sben^* = 3\%$. Table 4.30 shows the percentage increase or decrease in the optimal solution at different of values of cost parameters.

From Table 4.29, we can see that the buyer's inventory holding inventory cost, r_b, and the selling price, C_B, are the most influential cost parameters and have almost the identical effect on the shipment size q.

Table 4.30
The Effect of Cost Parameters on the Outcome Variables

	As	Ab	rb	Rs	Zb	Zs	Cb	Cs	Lb	pr	dr
-50%											
Qj	5%	4%	55%	-6%	-14%	-21%	54%	-6%	-1%	-12%	6%
TRCj	-11%	-8%	-14%	-11%	-3%	-5%	-17%	-11%	-2%	-15%	6%
Bben	-75%	177%	-85%	250%	17%	-66%	-96%	250%	-25%	402%	-51%
Sben	-81%	236%	-82%	168%	32%	-67%	-95%	168%	-22%	244%	-46%

	As	Ab	rb	Rs	Zb	Zs	Cb	Cs	Lb	pr	dr
-25%											
Qj	2%	2%	20%	-3%	-7%	-10%	19%	-3%	0%	-4%	3%
TRCj	-5%	-4%	-7%	-5%	-1%	-2%	-8%	-5%	-1%	-4%	3%
Bben	-35%	71%	-47%	81%	7%	-33%	-57%	84%	-13%	63%	-30%
Sben	-43%	86%	-42%	63%	13%	-34%	-52%	65%	-11%	50%	-26%

	As	Ab	rb	Rs	Zb	Zs	Cb	Cs	Lb	pr	dr
25%											
Qj	-2%	2%	-13%	2%	6%	10%	-12%	2%	0%	2%	-3%
TRCj	5%	-4%	6%	5%	1%	2%	7%	5%	1%	2%	-3%
Bben	28%	71%	49%	-47%	-6%	32%	63%	-47%	13%	-25%	44%
Sben	42%	86%	39%	-42%	-10%	33%	49%	-42%	11%	-22%	35%

	As	Ab	rb	Rs	Zb	Zs	Cb	Cs	Lb	pr	dr
50%											
Qj	-4%	-3%	-22%	5%	13%	19%	-21%	5%	1%	4%	-6%
TRCj	10%	7%	12%	10%	3%	4%	14%	10%	2%	4%	-7%
Bben	51%	-76%	98%	-73%	-10%	62%	127%	-73%	26%	-38%	111%
Sben	82%	-79%	75%	-68%	-17%	64%	94%	-68%	21%	-33%	83%

If we increase either r_b or C_B, the shipment size q will decrease. Also, we can see that the production rate, p_r, has the largest effect on the total relevant cost TRC and on the buyer's benefits Bben. Ordering costs have the most significant impact on supplier benefits.

Further investigations have been made to find the best value for k which provides the minimum total relevant cost. The results reveal that this is when k=1 is

the optimal, which means that the optimal lot size and shipment size are equal. Figure 4.23 shows how the total relevant cost depends on the value of k.

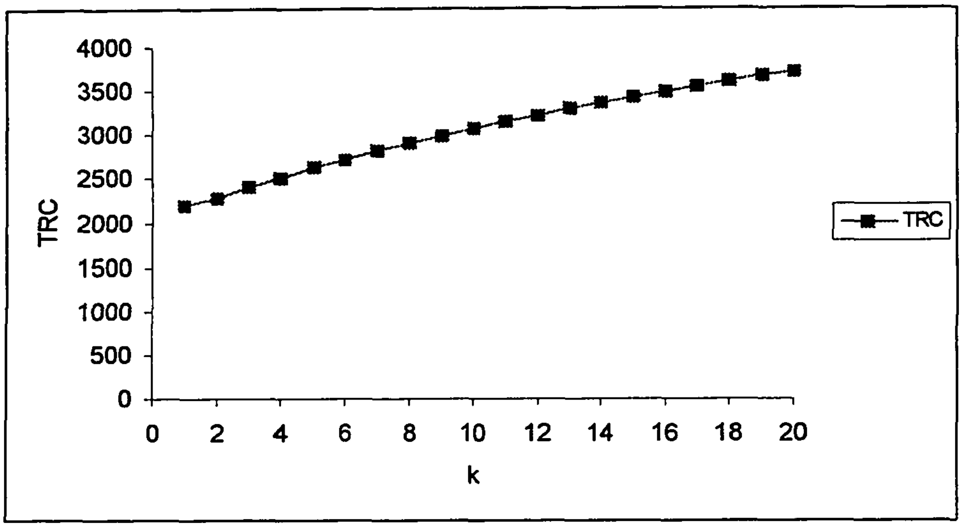

Figure 4.23
Total Relevant Costs with Different Values of k

Figure 4.24 shows the effect of the customer service level, α, on the optimal total relevant cost TRC and the optimal shipment size q. The larger the value of α, the larger the total relevant cost and the smaller the shipment size.

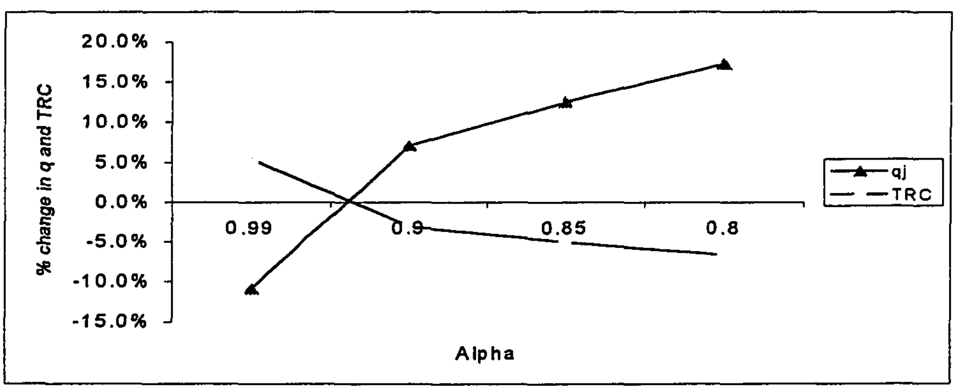

Figure 4.24
Total Relevant Cost and Shipment Size with Different Values of α

4.3.4 Numerical and Managerial Analysis when the Supplier is Holding Safety Stock (Model 4)

In Section 3.4.4, we considered the situation where the supplier relies on a safety stock of finished goods to meet the buyer's shipment request on time, according to the JIT delivery agreement. This is typical in the transition state to JIT, when the supplier may have capacity, flexibility, quality, or scheduling problems preventing on time delivery. In this section, first, we provide the numerical solution for the base-case set of parameters introduced in Section 4.1 and used previously in the other models to compare different scenarios. Next, we give sensitivity and managerial analysis of Model 4.

If the buyer is strong, we can find the optimal values for the shipment size, q, and the number of shipments, n, respectively, using expression (20) and expression (26). The optimal number of shipments for the buyer is n=7 and the optimal shipment size, q, is 76. The numerical and cost results are summarized in the first column of Table 4.25. The buyer's total cost is \$599 and using the buyer's optimal the supplier total cost is \$2015.

Similarly, if the supplier is strong, then the supplier can chose its best lot size as an integer multiple of the shipment quantity, $Q_S = mq_B$. The numerical and cost results are summarized in the second column of Table 4.31. It shows the optimal shipment size q_s = 28, and the number of shipments per lot size, m=7, for the supplier, using expression (65) and expression (68). The supplier's total cost is \$ 1613. If the buyer must accept the optimal lot size of the supplier, $Q_S = q_S$ as the shipment size, the buyer's total cost is \$ 748.

Table 4.31
Optimal Ordering Policies and Relevant Costs

Policy	Buyer's Optimal	Supplier's Optimal	Joint optimal
K	-	-	1
Number of shipment per order n	7	-	7
Number of shipment per lot size m	-	7	7
Shipment size q	76	28	46
Order quantity Q_B	532	-	322
Production lot size Q_S	-	196	322
Buyer's TRC	599	748	675
Supplier's TRC	2015	1613	1643
Overall TRCJ	2614	2361	2318
Buyer's Loss	-	25%	13%
Supplier's loss	25%	-	2%

For the joint optimal policy of the two parties, we use the results in Section 3.4.4. From expression (120), we find the optimal values for the shipment size, q, and the value of n, and m, respectively, using an iterative calculation. The optimal value of n and m is the same, 7. The optimal shipment size is $q_J^* = 46$. If the two parties accept the joint shipment size, the total costs for the buyer is $TRC_B(q_J^*) =$ \$675, for the supplier $TRC_S(q_J^*) =$ \$1643, and the total system cost is the minimum, \$2318. Thus, the total system cost can be decreased by \$296 (13%) if the two parties are ready to switch from the buyer's optimal policy to the joint optimal policy. Similarly, the total system gain is \$43 (2%) by switching from the supplier's optimal policy to the joint optimal policy.

As in the previous section, we examine the three different scenarios in negotiation, now considering the case when the supplier holds safety stock.

a.) If the **supplier is strong**, the supplier will urge the buyer to agree to order the supplier's optimal lot size as the shipment size. In this case, the buyer is willing to negotiate with the supplier for the acceptance of the joint order quantity in order to minimize the loss that is incurred by using the supplier's optimal lot size as the shipment size. The buyer could have a cost decrease up to $ 43 (6%) after compensating the supplier for its loss. The costs are summarized in Table 4.32.

Table 4.32
Moving from Supplier's Optimal to Joint Optimal

	Buyer's Cost	Supplier Cost	Total Cost
Supplier Optimal	748	1613	2361
Joint Optimal	675	1643	2318
Cost Improvement	73	-30	43
Compensation	-30	30	0
Buyer Benefit	43	-	43
Bben%	6%	-	-

b.) Similarly, we examine the case where the **buyer is stronger** than the supplier. In this case, the supplier is willing to make some sort of concession, such as a price discount, to the buyer to encourage the latter to accept the joint order quantity. The supplier could have a cost decrease of up to $296 (3%) after compensating the buyer for its loss. Table 4.33 summarizes this result.

Table 4.33
Moving from Buyer's Optimal to Joint Optimal

	Buyer's Cost	Supplier Cost	Total Cost
Supplier Optimal	599	2015	2614
Joint Optimal	675	1643	2318
Cost Improvement	-76	372	296
Compensation	76	-76	0
Supplier Benefit	0	296	296
Sben%		15%	

c.) If the **buyer and supplier are willing to coordinate**, and adjust their policy to the optimal joint shipment size, a gain of 15% can be achieved relative to the supplier's optimal policy in this numerical example. We will explore this issue later in more detail considering several different parameters.

Similarly, as in previous sections, we evaluate the effect of the cost parameters on the joint optimal solution. We use the cost information from the previous example with the base-case parameter values used in each comparison. The values for the optimal solution are $q^* = 46$, $TRC^* = 2318$, $Bben^* = 6\%$ and $Sben^* = 15\%$. Table 4.34 shows the percentage increase or decrease in the optimal solution for different of values of the cost parameters.

From Table 4.34, we can see that the buyer's inventory holding cost, r_b, the purchase price, C_B, and shipping cost for the supplier, Z_S, are the most influential cost parameters on the shipment size q. The first two parameters have almost an identical effect on the shipment size q. The same results were revealed in Model 3. If we increase either r_b or C_B, the shipment size q will decrease. In the opposite, as we increase the shipping cost for the supplier, the shipment size, q, increases. Also, we can see that the unit production cost, C_S, and inventory holding cost for the supplier, r_s, have the largest effect on the total relevant cost TRC. The ordering cost, A_B, and the setup cost, A_S, have the most significant impact on buyers benefit Bben% but in opposite directions. As the setup cost increases, the buyer's benefit decreases. In contrast, an increase in ordering cost provides a reduction in the buyer's benefit. Finally, the set up cost and the purchase price, C_B, have the largest effect on supplier benefit.

Table 4.34
The Effect of Cost Parameters on the Outcome Variables

	As	Ab	rb	rs	Zb	Zs	Cb	Cs	Lb	pr	dr
-50%											
qj	-4%	-3%	15%	8%	-8%	-18%	16%	8%	1%	-11%	5%
TRCj	-10%	-7%	3%	-24%	-4%	0%	1%	-24%	-2%	-8%	7%
Bben	127%	-73%	36%	-53%	-8%	23%	57%	-53%	19%	-6%	7%
Sben	64%	-63%	60%	-63%	-6%	26%	103%	-63%	28%	-9%	10%

	As	Ab	rb	rs	Zb	Zs	Cb	Cs	Lb	pr	dr
-25%											
qj	-2%	-1%	7%	7%	-4%	-6%	7%	7%	0%	-2%	2%
TRCj	-5%	-3%	1%	-13%	-2%	-3%	0%	-13%	-1%	-5%	3%
Bben	47%	-37%	17%	-28%	-4%	4%	26%	-28%	9%	-6%	4%
Sben	28%	-28%	26%	-36%	-3%	3%	41%	-36%	13%	-9%	6%

	As	Ab	rb	rs	Zb	Zs	Cb	Cs	Lb	pr	dr
25%											
qj	2%	1%	-6%	-6%	4%	5%	-6%	-6%	0%	2%	-2%
TRCj	4%	3%	-1%	12%	2%	3%	0%	12%	1%	3%	-3%
Bben	-30%	36%	-15%	20%	4%	-4%	-22%	20%	-8%	3%	-5%
Sben	-22%	22%	-20%	31%	2%	-2%	-28%	31%	-12%	4%	-6%

	As	Ab	rb	rs	Zb	Zs	Cb	Cs	Lb	pr	dr
50%											
qj	3%	3%	-10%	-10%	7%	10%	-11%	-10%	-1%	3%	-3%
TRCj	8%	6%	-1%	23%	4%	5%	1%	23%	2%	5%	-7%
Bben	-51%	71%	-26%	36%	7%	-7%	-39%	36%	-16%	5%	-10%
Sben	-39%	39%	-33%	59%	5%	-4%	-49%	59%	-22%	7%	-14%

Further investigations have been made to find the best value for k which provides the minimum total relevant cost. The results reveal that k=1 is optimal, which means that the optimal lot size and shipment size are equal. Figure 4.25 shows the relationship between the total relevant cost and the value of k.

Figure 4.26 shows the effect of the customer service level, α, on the optimal total relevant cost TRC and the optimal shipment size q. The larger the value of α, the larger the total relevant cost and the smaller the shipment size.

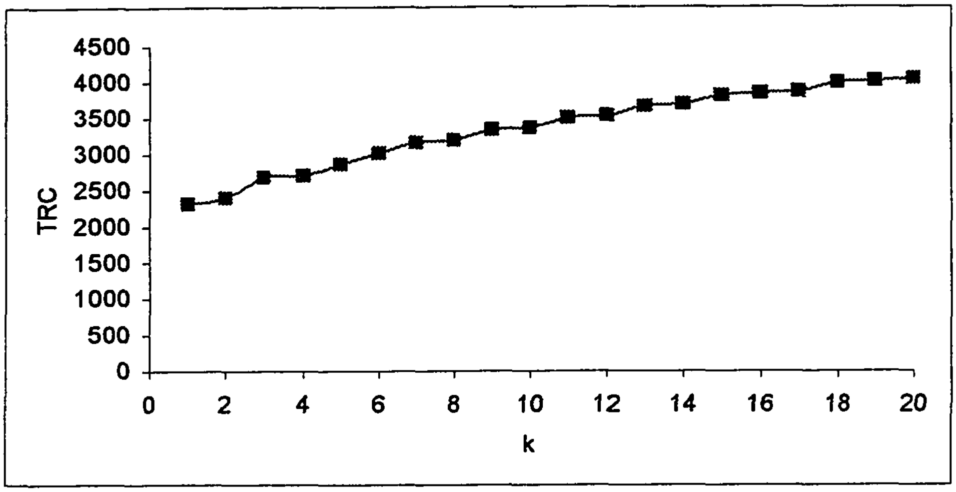

Figure 4.25
Total Relevant Costs with Different Values of, k

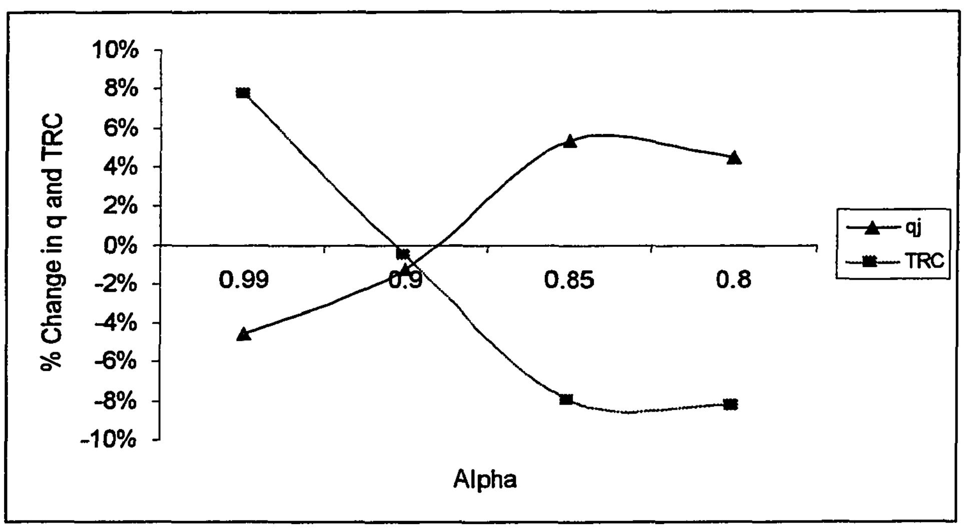

Figure 4.26
Total Relevant Cost and Shipment Size for Different Values of ,α

Further analyses have been made to identify the cost parameters that have the most significant effect on the joint optimal solution. The numerical results reveal that the inventory holding cost for the supplier, r_s, is the most influential cost parameter on the joint optimal value of the total relevant cost, TRC_j. As we increase the inventory holding cost for the supplier, r_s, the total relevant cost TRC_j will increase. The relationship is nearly linear and is expressed in equation (136) with $R^2 = 0.999$. The form of the relationship is illustrated in Figure 4.27.

$$TRC_j\ \% = 0.4869\ (r_s\ \%) - 0.007 \qquad (136)$$

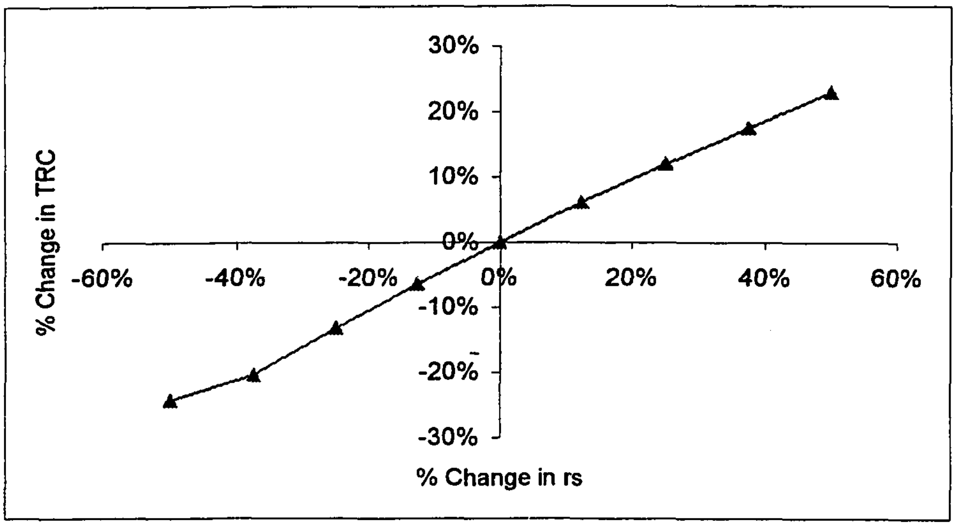

Figure 4.27
The Relationship Between % Change in r_s % Change in TRC

Also, we find that the shipping cost for the supplier, Z_s, and selling price, C_B, cause the highest incremental changes in the joint optimal shipment size, q_j. The shipment size increase is close to linear with the decrease of the cost parameter C_B. The regression line (137) describes this relationship where $R^2 = 0.995$. The shipping cost, for the supplier, Z_s, has opposite effect on the shipment size as it is described by the linear regression line, (138). Figure 4.28 shows these relationships.

$$q_j\% = 0.0119 - 0.2685\,(C_B\,\%) \quad (137)$$

$$q_j\,\% = 0.2516\,(Z_s\%) - 0.0119 \quad (138)$$

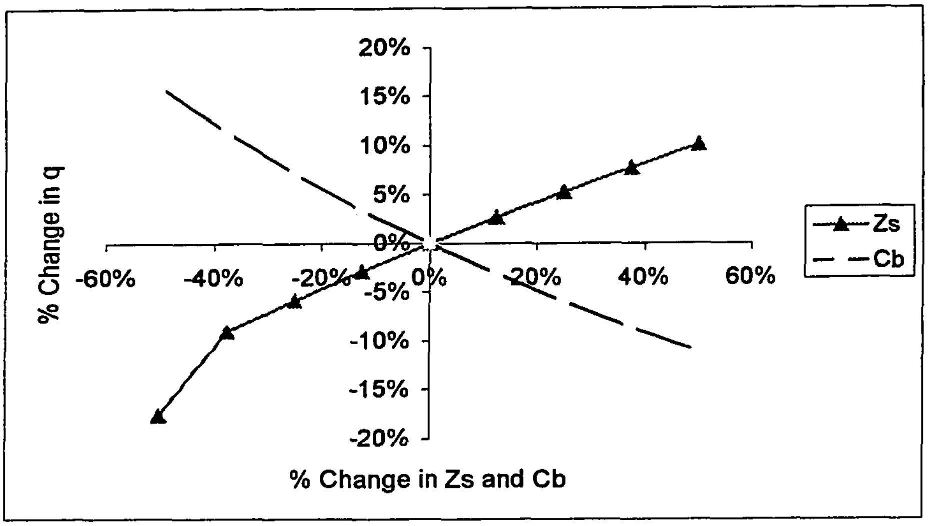

Figure 4.28
The Relationship Between % Change in Zs and C_b with % Change in q

Figure 4.29 illustrates how the changes in the setup cost, A_S, and the ordering cost, A_B, will affect the buyer's percentage benefits, Bben%. As the setup cost, A_S, increases, Bben% decreases whereas the change in the ordering cost yields the opposite behavior. The relationship between the setup cost and ordering cost with buyer's benefit is expressed in equations (139) and (140), respectively. Figure 4.29 describes these relationships.

$$Bben\% = 1.5568\,(A_S\,\%)^2 - 1.698\,(A_S\%) - 0.0107 \quad (139)$$

$$Bben\% = 1.45398\,(A_B\,\%) - 0.008 \quad (140)$$

In regard to the supplier's benefit, Sben, the purchase price, C_B, and the production cost for the supplier, C_S, are the most significant cost parameters affecting the supplier's benefit. As shown in Figure 4.30, the supplier's benefit increases as the supplier price, C_S, increases and the supplier's benefit decreases as

the buyer price, C_B, increases. These relationships can be expressed with the regression lines (141) and (142), respectively:

$$Sben\,\% = 1.2787\,(C_S\%) - 0.0255 \tag{141}$$

with $R^2 = 0.997$ and

$$Sben\% = 1.0889\,(C_B\%)^2 - 1.4723\,(C_B\%) \tag{142}$$

with $R^2 = 0.999$

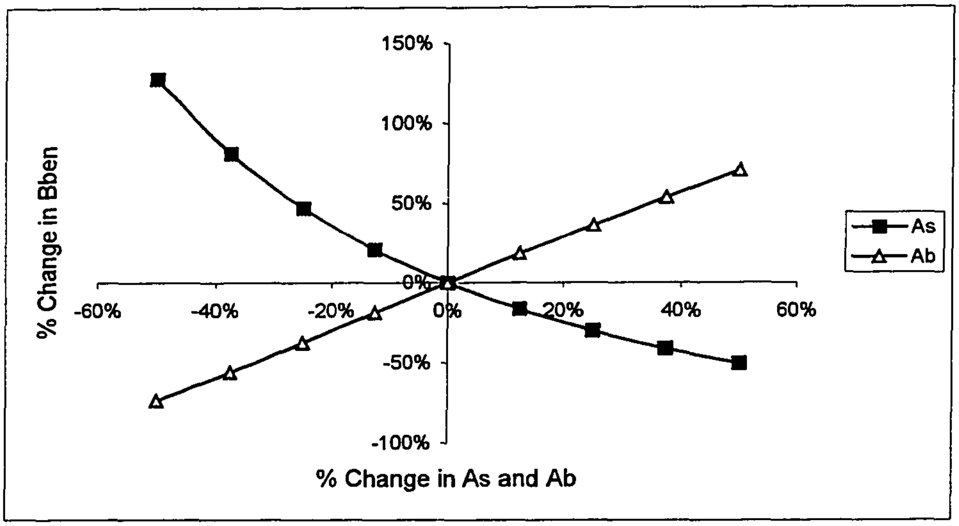

Figure 4.29
The Relationship Between % Change in A_S and A_B with % Change in %Bben

4.4 Comparison of the Four Models

In this section, we compare the costs, benefits, and the optimal decision variables of the four basic models. These models are:

a.) Deterministic case with the same number of setups and deliveries, hence, n = m (Model 1, described in Section 3.4.1)

b.) Deterministic case with different number of setups and deliveries (Model 2, described in Section 3.4.2)

c.) Transition to JIT when the buyer is holding safety stock (Model 3, described in Section 3.4.3)

d.) Transition to JIT when the supplier is holding safety stock (Model 4, described in Section 3.4.4)

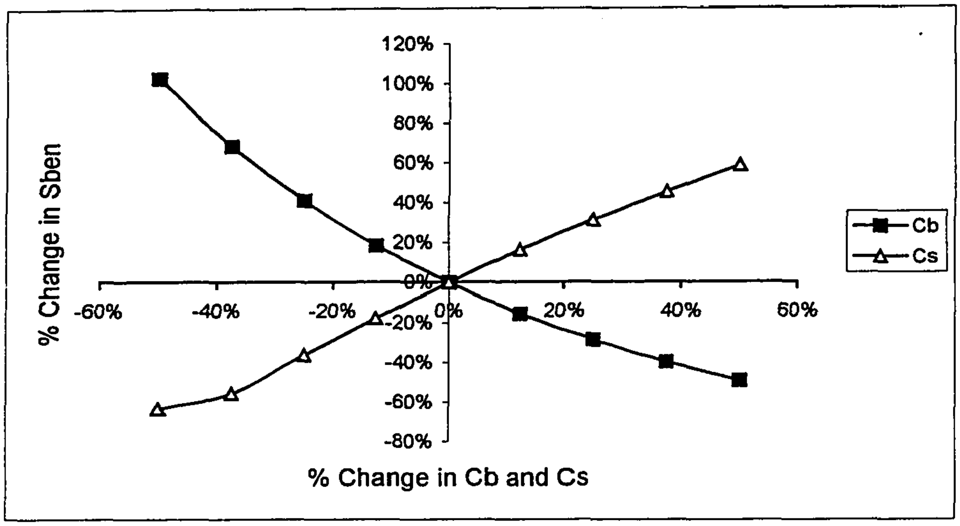

Figure 4.30
The Relationship Between % Change in Cb and Cs with % Change in %Sben

Numerical results reveal that the optimal number of deliveries is the largest and the optimal shipment size is the smallest for Model 3. Since Model 3 and Model 4 include the necessary safety stock required to meet the customer service prescribed, they have largest joint total cost compared to Model 1 and Model 2, which do not include safety stocks. Model 4 has the largest total joint cost compared to the other models, and Model 2 offers the largest saving for the buyer when the buyer and supplier accept the joint optimal policy. In contrast, Model 4 offers the largest saving for the supplier when the buyer and the supplier in this case. An illustration of the numerical results is shown in Table 4.35.

In examining the cost parameters involved for the buyer and the supplier in the four models, we recognize some common tendencies. Each party has the lowest cost for their optimal order quantity, and each party, also, has the highest cost if the other party's optimal solution is applied. If the joint optimal solution is agreed upon, it provides the best compromise. Each party does not benefit as much as they would if their optimal values are adopted, however, the joint total cost is lower than if the other party's optimal order quantity is ordered or any other policy is applied. This fact is the basis of negotiations and motivation for JIT Partnership.

Table 4.35
Comparison of the Four Models

Policy	Model-1	Model-2	Model-3	Model-4
K	-	-	1	1
Number of shipment per lot size m	16	12	26	7
Number of shipment per order n	16	23	26	7
Shipment size q	34	38	17	46
Order quantity Q_B	544	874	442	322
Production lot size Q_S	544	456	442	322
Buyer's TRC	510	494	1116	675
Supplier's TRC	1010	983	1089	1643
Overall TRCJ	1520	1477	2205	2318
Bben%	40%	44%	3%	6%
Sben%	6%	10%	3%	15%

Next, we compare Model 1 with the new extension Model 2. The optimal number of deliveries and the delivery size is larger for Model 2 than model 1. It also offers a larger savings for both parties if either party accept to move from the optimal policy of the other party to the joint optimal than model 1. An illustration of this is given in Table 4.36.

Table 4.36
Comparison Between Model-1 and Model-2

Policy	Model-1	Model-2	Rate of change
Number of shipment per lot size m	16	12	-25.0%
Number of shipment per order n	16	23	43.8%
Shipment size q	34	38	11.8%
Order quantity Q_B	544	874	60.7%
Production lot size Q_S	544	456	-16.2%
Buyer's TRC	510	494	-3.1%
Supplier's TRC	1010	983	-2.7%
Overall TRCJ	1520	1477	-2.8%
Bben%	40%	44%	10.0%
Sben%	6%	10%	66.7%

In regard to comparisons between Model 3 with the new extension, Model 4, the results show that the total joint cost under Model 3 is smaller than in Model 4. This result can be justified by the fact that the supplier can hold safety stock more economically to meet the demand of several buyers rather than the buyer can hold safety stock for every supplier. The optimal number of deliveries is smaller for Model 4 and the delivery size is larger than in Model 3. Model 4 offers larger savings for both parties than Model 3 if either party accepts the move from the optimal of the other party to the joint optimal. An illustration of this is given in Table 4.37.

The effect of changes in cost parameter values on the total joint cost is also of interest. We examine the parameter effects on the percentage total joint cost changes between Model 1 and Model 2 together, and then between Model 3 and Model 4 together.

Table 4.37
Comparison Between Model-3 and Model-4

Policy	Model-3	Model-4	Rate of change
k	1	1	0.0%
Number of shipment per lot size m	26	7	-73.1%
Number of shipment per order n	26	7	-73.1%
Shipment size q	17	46	170.6%
Order quantity Q_B	442	322	-27.1%
Production lot size Q_S	442	322	-27.1%
Buyer's TRC	1116	675	-39.5%
Supplier's TRC	1089	1643	50.9%
Overall TRCJ	2205	2318	5.1%
Bben%	3%	6%	100.0%
Sben%	3%	15%	400.0%

In Model 1 and Model 2, the setup costs for the supplier and the cost per unit for the buyer has the largest effect on the percentage change of the total joint cost. The results reveal that as we decrease the setup cost for the supplier or the cost per unit for the buyer, the percentage change in the total joint cost between Model 1 and Model 2 increases. The latter provides the smallest increase in the percentage change in the total joint cost. Also, the demand rate and production rates have an inverse effect on the percentage change in the total joint cost. An illustration is shown in Table 4.38. The new extensions always have the lowest total optimal joint cost; however, there is a smaller difference than we expected. This can be the result of the low sensitivity to changes of the EOQ type order quantity models. The robust model results in small cost differences.

We now examine the effect of changing the cost parameter values on the total joint cost using Model 3 and Model 4. Table 4.39 shows that the inventory holding cost for the supplier has the largest effect on the percentage change in the total joint

cost, as we would expect. As the inventory holding costs increases, the percentage change in total joint cost decreases.

Table 4.38
Savings Achieved in TRC by Model 2 Compared to Model 1

	As	Ab	Rb	rs	Zb	Zs	Cb	Cs	Lb	pr	dr
-75%	11%	0%	3%	0%	3%	1%	6%	0%	7%	0%	5%
-50%	6%	1%	3%	1%	3%	2%	4%	1%	5%	1%	4%
-25%	4%	2%	3%	2%	3%	2%	3%	2%	4%	2%	4%
25%	2%	3%	3%	3%	3%	3%	2%	3%	2%	3%	2%
50%	2%	4%	3%	4%.	3%	3%	2%	4%	2%	3%	1%
75%	1%	4%	3%	4%	2%	3%	1%	4%	1%	4%	1%

Table 4.39
Comparison Between Model 3 and Model 4 with respect to TRJC

	As	Ab	rb	rs	Zb	Zs	Cb	Cs	Lb	pr	Dr
-75%	0%	-7%	-25%	38%	-9%	-8%	-26%	38%	-5%	-13%	-6%
-50%	-7%	-6%	-21%	11%	-4%	-9%	-21%	11%	-5%	-12%	-6%
-25%	-6%	-5%	-13%	4%	-4%	-4%	-12%	4%	-5%	-5%	-5%
25%	-4%	-4%	2%	-11%	-5%	-6%	2%	-11%	-5%	-5%	-5%
50%	-4%	-4%	8%	-15%	-6%	-6%	8%	-15%	-5%	-5%	-5%
75%	-9%	-4%	7%	-19%	-6%	-7%	7%	-19%	-5%	-5%	-11%

CHAPTER 5
JIT PARTNERSHIP WITH THE USE OF AN ELECTRONIC DATA INTERCHANGE AND ACTIVITY BASED COSTING

5.1 Introduction

This chapter intends to lay the theoretical groundwork for the integration of ABC and EDI with JIT partnership. Therefore, this chapter is divided into two sections: the first section reviews and compares the concept of ABC to JIT partnership and the second section covers the use of EDI in a JIT environment.

In the first section, we will outline the major differences between a traditional costing system and an activity-based system. Using a numerical example, we demonstrate that ABC can provide management with more accurate information than the traditional costing system concerning the costs and benefits of implementing JIT partnership. Next, we specify the cost activities, cost drivers, and traceable costs in order to examine the effect of using ABC in evaluating the costs and benefits of using JIT to buyers and suppliers.

In the second section, we will address the following issues: definition of EDI, the importance of sharing information to a JIT Partnership, the economic feasibility of implementing such technology, and the benefits of adopting EDI in a JIT environment.

5.2 Activity Based Costing System and JIT Partnership

One of the major problems associated with JIT models that are developed in operations management is that companies lack the appropriate data to quantify the costs and benefits of implementing JIT partnerships. In the past, a traditional costing system has typically has been applied to collect such data. Since this method is

unable to keep track of all cost items that are associated with inventory costs, a new method emerged in the early 1990s, called Activity Based Costing accounting system (ABC). CAM-I (the Consortium for Advanced Manufacturing-International) defines ABC as a method recognizing the causal relationship of cost drivers to cost activities by measuring the cost and performance of process-related activities and cost objects (Holmen, 1995). We apply this method in our study, since we believe that ABC overcomes most of the shortcomings of traditional costing systems and, also, accommodates the changes in the cost structures of the inventory costs.

5.2.1 Traditional Costing System versus ABC System

A traditional costing (TC) system defines the cost of a product as including those elements that constitute the dollar values assigned to manufacture products for inventory valuation and external reporting. Under this definition, product cost consists of three major elements: direct material, direct labor, and manufacturing overhead. Direct materials and direct labor costs are considered to be traceable directly to the product. But, manufacturing overhead of both production and management service departments is treated as an indirect cost of the product and is charged to the product by use of predetermined overhead rates (e.g., direct labor hours) (Harris, 1990). The traditional cost accounting method assumes that all overhead resources are used at the same rate proportionally with the driver costs by all products. Therefore, many experts believe that the amount of overhead cost allocated is inaccurate (Horngren, et.1994). The assumptions of traditional costing usually are inaccurate because, for example, some products, relative to others, require more or less engineering support, setup time, or data processing, etc. When

the cost system, either the one used within the accounting department or the one embedded within an MRPII system, allocates overhead this way, the result is distorted costs. For example, frequently low-volume and specialty products are under cost and high-volume and standard products are over cost (Cooper, 1988).

In an ABC costing system, the focus is on measuring the costs of activities that consume resources. Once the activities' costs are identified, the activities are traced to the products that caused the activities. Costs are then assigned to the products based on their share of the activities generated. More accurate product costs are the result of an ABC costing system. Therefore, the company is in a better competitive position because it can determine more accurately its products' costs. Parenthetically, it might be noted that this development could be used to their advantage by purchasing negotiators in cost analysis work.

Under the JIT philosophy, there are some unnecessary activities like inspecting parts when they are delivered by the vendor, and placing them on shelves on in the stockroom. Eliminating these activities reduces the overall cost and the cost of the products that no longer required such activities. ABC provides a good estimate of the cost of eliminated unnecessary activities. The cost of inspection activity, for example, is likely to be identified separately. If inspection activity is eliminated, the ABC system will reveal both the overall reduction in cost and the specific source of the cost reduction. On the other hand, a traditional cost system is unlikely to reveal the potential cost saving that comes from eliminating activities. The cost savings are typically buried in large overhead pools that do not reveal the source behind cost reduction. Finally, cost control is also improved because costs are identified with the

activities that incurred the costs. Better-cost control is facilitated by use of an ABC costing system. These factors clearly can lead to increased profitability and competitiveness.

5.2.2 The ABC Method of Determining Unit Costs

The process that ABC follows in allocating manufacturing overhead to actual units produced differs from that used under TC. ABC divides manufacturing overhead into four different levels of activities: unit-level activities, batch-level activities, product-level activities, and facility-level activities (Cooper, 1990).

Unit-Level Activities: Unit level activity changes in proportion to the number of units produced. Usually, TC takes into account unit-level activities, but ABC often includes many new unit-level activities that typically are not identified separately in TC. For example, the number of inspection times and the pounds of material handled are unit-level cost drivers for inspection and material handling.

Batch-Level Activities: Batch-level activities are performed for each batch of product processed. The amount of batch-level activity performed depends on the lot size. For a given product, if a lot size is small, more batches will have to be processed to meet a given level of demand. Therefore, a product produced in shorter runs will require more batch-level activity. The common batch-level activity is a machine setup. Once a machine has been set up for a production run, it can be used to produce one, 1,000 or 10,000 units. As a result, the total setup cost varies with the number of setups or batches and not with the number of units produced. Many other examples of batch-level activity exist in different operations, such as, the schedule time and the assembly setup time.

Product-Level Activities: Product-level activities are those that are performed for specific product types. These activities and associated costs do not vary with respect to the number of units produced or the number of batches run. Some examples include the number of raw material shipments received, number of finished goods shipments made, number of purchased orders received, and number of part numbers (Sherrad and McEwen, 1997).

Facility-level activities: Any costs that do not vary with unit-level, batch-level, or product-level activity are considered to be true facility-level activities. Examples include plant supervision, and building occupancy, providing utilities, and providing space for inventory. These costs are common to a variety of products and are the most difficult to link to product-specific activities.

5.2.3 Implementation of the ABC

Activity-Based Costing, as the name suggests, traces the cost to the cost objects (products, customers, etc.) through activities. This is in contrary to traditional cost accounting, which traces costs directly to products. Activities, rather than products, consume resources and the demand for those activities in the manufacturing process determine how the costs are allocated to the individual cost objects. Resources include all the costs recorded by the accounting system in carrying out daily business, such as salaries, materials and, overhead (rent utilities, insurance, advertising, etc.). Activities are procedures that are carried out in order to manufacture a product or provide a service.

The business process can be broken down into several activities. Typically, these activities are grouped by function and each group is referred to as an activity center. Cost objects are the final result of the business process.

The two-stage cost assignment, from resources to activities and then from activities to cost objects, is based on multiple cost drivers, such as number of setups, square footage of warehouse space, number of purchase orders, machine hours, number of parts, number of defects, etc. Cost drivers are the bases used to make cost assignments and can be resource drivers or activity drivers, depending on whether we are allocating resource costs to activities or activity costs to products, respectively. Cost drivers are selected to reflect the cause-and-effect relationships in the manufacturing process. While traditional cost accounting allocates costs to products using volume cost drivers, ABC recognizes that costs may be driven by other factors, such as complexity.

Direct labor and direct materials can be allocated the same way under either traditional cost accounting or ABC, but overhead allocation is much more sophisticated under ABC, since it allows for multiple cost drivers. As a result, the ABC product costs can be radically different from those of the traditional cost accounting system. For example, traditional cost accounting will undercost a complex, low volume product, subsidizing its cost by allocating most of the overhead to high volume, standard products. The result can lead to incorrect decisions about product mix, pricing and process improvement. ABC is able to provide a more refined and " accurate" view of process costs helped by the widespread use of computer technology in manufacturing environments. This

enables companies to economically compile the multiple cost driver information needed for the ABC system.

If we look at the allocation rates used in any cost accounting systems (including ABC) we note that they are stated in terms of dollars per unit. The numerator is the cost of resources or activities (in dollars) and the denominator is a measure of how the resource or activity is consumed (for example, time, number of parts, dollars, etc.). In ABC, the denominators used to allocate resource dollars to activities are called resource drivers, and those used to allocate activity dollars to products are called activity drivers. Figure 5.1 illustrates the ABC allocation of costs to products (or cost objects).

Let the dollar amount of each resource cost pool k be C_{Rk}. Then, the total cost of resources to be assigned to products (or any other cost objects) will be: $\sum_k C_{Rk} = C$. The actual amounts are usually obtained from the accounting records, such as the general ledger, or the operating budget for each department. The first step is to assign the resource dollars in each department to the activities performed in that department.

Each cost pool within the department uses a different resource driver or allocation base in order to distribute C_{Rk}. For example, if we want to allocate fuel costs, we might use number of gallons as our allocation base. Let r_{kj} be the amount of resource k driver (allocation base) consumed by activity j (the number of gallons consumed by each activity).

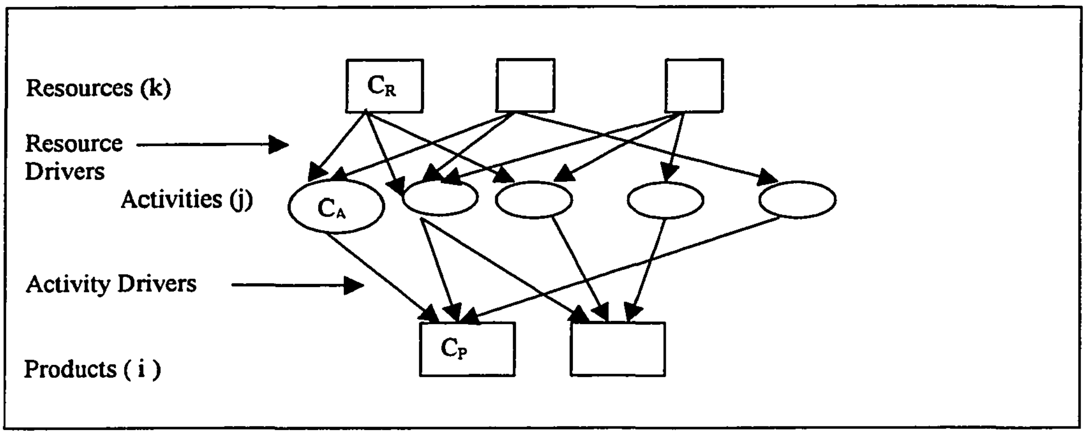

Figure 5.1
Activity-Based Cost Allocation

Then, the total allocation base for resource k is: $\sum_j r_{kj} = r_k$ (The total number of gallons used by the department) and the allocation rate for resource k will be C_{Rk}/ r_k (dollars / gallon). The dollar amount allocated from resource k to activity j is calculated as $C_{Rk}\left[{r_{kj}}/{r_k} \right] = C_{rkj}$. We do this for all the resources to arrive at the cost of the activities. Thus, each activity j has a total dollar cost of $\sum_{k=1}^{l} C_{rkj} = C_{Aj}$.

Next, we will allocate the cost of each activity to the products that demand that activity. Suppose the activity is material transfer, which included fuel costs, as well as other resource costs then we might choose to allocate the costs of this activity based on the number of trips. Let a_{ij} be the amount of activity j driver (trips) consumed by product i (for simplicity, assume each trip can only accommodate one type of product). Then, the total activity driver (total number of trips) for activity j is $\sum_i a_{ji} = a_j$ and the allocation rate for j is C_{Aj} / a_j (dollars / trip). The cost of activity j

allocated to product i is calculated as $C_{aj}\left[{a_{ji}}/{a_j}\right] = C_{Aji}$ and the total cost of product i will be $\sum_j C_{Aji} = C_{pi}$.

Note that it is possible (and often necessary) to allocate the cost of one or more activities to other activities, rather than directly to products. This will be the case for support activities or departments such as maintenance or personnel. In this case, the total cost of some activities would include not only C_{Rkj} dollars, but also some C_{Aji} dollars (where the cost of activity j had been allocated to activity i)

5.2.4 An Example of ABC Application

A simple example can be used to (1) illustrate the difference between traditional costing and ABC, and (2) demonstrate a complete application of these new ABC methods in a product costing system. Suppose a company manufactures three products: A, B, and C. The products differ in batch sizes (volume). Assume that the company's \$ 10 million indirect manufacturing expenses (overhead resources) is to be allocated to the three products A, B, and C. (this example is limited to overhead resources, since direct materials and labor are assumed to be allocated directly to the product).

Table 5.1 shows the allocation of these resources directly to each product using a traditional cost accounting system based on machine hours. Suppose that four activities consume the resources: purchasing, planning, receiving, and production inspection. Table 5.2 shows the activities and associated total costs and cost drivers.

Table 5.1
Traditional Overhead Allocation ($ millions)

Product	Volume	Mach hours (hr)	O/H rate ($)	Allocation ($ Millions)	Cost/Unit $/unit
A	2000	200	10000	2	$ 1000
B	2000	300	10000	3	$ 1500
C	4000	500	10000	5	$ 1250
Total		1000		10	

Table 5.3 shows the assignment of the cost drivers (unit per cost object). In Table 5.4, the allocation of the costs of the activities to each of the products is given. Note the significant differences in the cost per unit of products A and C. Such changes in product cost are typical when an ABC system is implemented and a more accurate allocation of overhead is made.

Table 5.2
Activities and Associated Total Costs and Cost Drivers ($ millions)

Activities	Total Cost	Cost Driver
Purchasing	4	No. of purchase order (P.O)
Planning	2	No. unit produced
Receiving	1	No. of shipments
Production inspection	3	(No. of inspection per unit) x (No. of units produced)
	$ 10 M	

Table 5.3
Activity Cost Drivers (Units Per Cost Drivers)

Activity	Driver	A	B	C	Total
Purchasing	No. of purchase order (P.O)	300	100	100	500
Planning	No. unit produced	2000	2000	4000	8000
Receiving	No. of shipments	20	60	20	100
Production inspection	(No. of inspection per unit) x (No. of units produced)	12000	20000	8000	40000

Table 5.4
Cost Allocation to Products ($ millions)

Product	Purchasing	Planning	Receiving	Production inspection	Total	Cost/Unit
A	2.4	0.5	0.2	0.9	4.0	2000
B	0.8	0.5	0.6	1.5	3.4	1700
C	0.8	1.0	0.2	0.6	2.6	650
Total	4.0	2.0	1.0	3	10	

Looking at just product A, for example, the product required 300 purchase orders sent, 2000 units produced, 20 shipments received, and 12000 inspections performed, therefore the resulting overhead allocation (in $ millions) is as follows:

Purchasing	(300/500)	x	$4 = $ 2.4
Planning	(2000/8000)	x	2 = 0.5
Receiving	(20/100)	x	1 = 0.2
Production Inspection	(12000/4000)	x	3 = 0.9
		Total	$ 4.0

This example serves to illustrate that low-volume (relative to machine hours) products such as A and B can be under-priced by the traditional cost accounting system. The ABC analysis showed that these products, although requiring relatively little machining, still needed a significant portion of the other activities. This could be the case if the product is very complex or requires special handling. The old accounting system was, in essence, subsidizing the low volume products by allocating the overhead based on machine hours, when in fact, much of the overhead was independent of machine hours.

5.2.5 Specifying Cost Activities and Drivers from the Buyer's Prospective

The major motivator underlying the introduction of JIT by the buyer is the expected cost savings in inventory investment, storage, personnel, and wastage. The extent to which JIT will decrease physical inventory levels and their value will drive at least some of these scenarios which are presented in (Table 5.5). Identifying the underlying cost activities and cost drivers will help purchase managers focus their attention on them. Moreover, a well-developed ABC system will put buyers in a strong position to make relevant costing decisions. With carefully selected cost drivers and cost functions, changes in costs resulting from a change in activity can be seen more clearly (Chwen, 1998).

From Table 5.5, we see that the buyers will be relieved from supplier selection and any other related costs. Such costs are clerical and administrative costs for personnel. In addition, buyers will have a reduction in bidding activity and manual repurchasing activity. A number of order processes can be considered as a cost driver for quantifying these cost savings as a result of implementing JIT.

Moreover, by implementing JIT, the buyers will benefit by a reduction in the costs of storage, insurance, obsolescence and the opportunity cost of money invested in inventory. Also, the expenses of direct storage costs such as, rent, light, heat, and record keeping will be reduced. A pound of material or square foot of material occupancy can be considered as a cost driver for these activities. In addition to that, the buyers will not need to worry about the cost of expediting orders, premium transportation and lost sales due to late deliveries and, holding and administrative costs related to early deliveries.

5.2.6 Specifying Cost Activities and Drivers from the Supplier's Prospective

Implementing JIT causes additional costs for suppliers. The two major sources of cost increase are the increased setup cost and transportation cost due to frequent setups and shipments. Table 5.6 identifies the cost activities and cost drivers for the supplier that describe these additional costs incurred by implementing JIT. Using number of setups or hours of setup time and number of orders processed as cost drivers can quantify these additional costs for the supplier. Additional warehouse space may be necessary to maintain adequate inventories in order that reliable service can be guaranteed. As a result, the supplier will realize an increase in warehouse cost, insurance, taxes, and holding cost. In order to obtain high-quality materials or products in larger quantities to receive the best prices and guaranteed deliveries, the supplier must be financially secure. Hence, the cost of capital and opportunity cost will increase under JIT. It is worth mentioning that the buyer can reduce the burden of the additional cost on the supplier by encouraging the supplier

Table 5.5
Cost Drivers from Buyers Prospective

Cost Activity	Cost Driver	Under JIT Partnership	Level of Activity
ORDERING COSTS (A_B)			
Vendor selection, contract preparation, writing, recording, inspecting and receiving the order, processing of invoices and preparing of payment.	Number of orders processed, Number of vendors, Number of products.	Decreased	**Product -level Activity**
Inspecting the order	Number of inspections or hours of inspection time or number of tests	Decreased	**Batch-level Activity**
Placing the order in storage	Pound of material handled or number of material receipts	Decreased	**Batch-level Activity**
Transportation	Number of orders processed or pounds of material handled	Increased	**Batch- level Activity**
HOLDING COSTS (r_B)[1]			
Warehouse cost, insurance, taxes , spoilage, obsolescence, storage and handling cost, cost of capital, and opportunity cost	Pound of material handled or square foot of material occupancy or value of material	Decreased	**Unit- level Activity**
STOCK OUT COSTS:			
No Backorder Situation:			
Loss of customer goodwill, current sales, future sales, and loss of contribution to overhead.	Number of customers lost or value of lost customer's sales	Decreased	**Unit- level Activity**
Backorder Situation:			
Loss of future sales (customer inconvenience), cost of paper work to track the order, and emergency shipping costs.	Number of backorders or amount on backorder or period of Shortage	Decreased	**Unit- level Activity**

[1]Stock holding cost represents a percentage of cost per unit. Warehousing, spoilage, obsolescence, and other factors can be considered in calculating the stock holding cost factor.

to schedule their output runs in response to the buyer's needs and maintain a constant communication link to coordinate production and distribution schedules.

On the other hand, the suppliers chosen are relieved of the necessity of constantly bidding for work and can focus their time and attention on meeting the short run and long run delivery schedule. By implementing JIT, suppliers receive two major cost reductions through the process. As a result, the product flows into several tasks such as milling, cutting and assembly and these tasks are performed consecutively as the product moves from machine to machine. We recognize saving in two ways. First, material handling cost is minimized. Second, it becomes unnecessary to store partially completed units. Thus, work in process inventories is minimized since partially completed goods move smoothly from machine to machine along the flow line.

Finally, in choosing a cost driver for an activity center, managers must be sure that it accurately measures the consumption of activity for the various products of the company. If a high degree of correlation does not exist between the cost driver and actual consumption, then inaccurate costing will result.

5.2.7 Major Processes and Their Activities from the Buyer and the Supplier Prospective

The accuracy of ABC lies in using activities and cost drivers that accurately quantify the resources consumed or utilized by cost objects. To keep it simple, the following discussion summarizes the major processes and their activities from the buyer and supplier perspective, respectively. Generally, the number of activities in an ABC system would be much larger than those in the traditional system. The actual

Table 5.6
Cost Drivers from Supplier's Prospective

Cost Activity	Cost Driver	Under JIT Partnership	Level of Activity
SETUP COSTS (A_S)			
Equipment setups	Number of setups or hours of setup time, number of schedule changes.	Increased	**Batch-level Activity**
Maintenance cost that connected to setup	Machine hours or labor hours		**Batch-level Activity**
HOLDINGCOST (r_S)			
Warehouse cost, insurance, taxes, breakage, obsolescence, storage and handling cost, cost of capital, and opportunity cost.	Pound of material handled or square foot of material occupancy Value of inventory, Number of Parts Received, Number of Employees	Decreased	**Unit-level Activity**

number depends on what is necessary to accurately trace costs and to provide comprehensive information that is easy to interpret.

Buyer Perspective

1. Material Acquisition:

11 Vendor Selection

111 Qualify potential vendors

112 Obtain bids on materials

113 Select vendors

114 Contract preparation

12 Issue purchase order

13 Purchase order follow up

14 Receive/inspect materials

15 Issue payment to suppliers

16 Put material into storage

17 Handle stockout/backorder

18 Handle restock and scrap

Supplier Prospective

1 Manufacturing

11 Set up machine

111 Schedule jobs

112 Issue material requisition

113 Set up machine

114 Load material into machine

115 Operate equipment

2 Sales and Shipping

11 Pick and assemble order

12 Load order into carrier

13 Ship to customer

14 Handle return and damages

15 Sales order entry

16 Managing receivables

17 Sales order follow up

5.3 JIT Partnership with the Use of an Electronic Data Interchange System

As the business environment becomes increasingly competitive, companies look for ways to distinguish themselves from their competitor. Their focus is to ensure that the "final customer receives the right product, at the right cost, at the

right time, in the right condition, and in the right quantity". Several authors (Bowersox et al., 1990,1992; Capacino and Britt 1991;Ellarm 1992; Langley and Holcomb) have suggested that JIT partnerships have the potential to enhance a firm's competitive position. Others (Bowersox et al. 1988,La Londe and Cooper 1989) have suggested that applying state-of-the-art management information systems and information technology applications to JIT partnership functions are vital to a firm's success. More specifically, EDI has become vital to many manufacturers engaged in JIT delivery because of the speed and data accuracy capabilities that are provided. In addition, EDI has given companies competitive advantage by "improving on time performance and lowering error rates" (Cook, 1994).

5.3.1 Definition of EDI

"EDI is the inter-computer to computer communication of a standard business transaction in a standard format that permits the receiver to perform the intended transaction"(Kekre and Mudhopadhyay, 1992). In other words, EDI is a way to automatically exchange data between computer systems, thereby eliminating the duplication of manual data entry, increasing accuracy and speed, and eliminating process delays.

Under the above definitions, the concept of EDI does not include the transmission of electronic mail or other free form messaging activities. The information transmitted by EDI is in a specific format that will allow the receiver's computer application programs to directly perform standard business transactions on the data. For example, EDI can be used to electronically transmit purchase orders,

invoices, shipping notices, financial and payment information, and any other types of standard business information.

5.3.2 The Importance of Sharing Information in JIT Partnership

Information sharing refers to the extent to which critical, often proprietary, information is communicated to one's partner (Mohr and Spekman, 1994). Many researchers consistently recommend various channels of communication for successful JIT partnerships (Coyle, Badri, and Langley, 1996, Carter and Ferrin, 1995). These include open and frequent sharing of sensitive and confidential information, and information concerning the supplier's production related issues.

Newman (1988) argues that the sharing of information with suppliers should be the same as it would be shared internally, because suppliers are regarded as an extension of the JIT Manufacturer's operation. Discussions and sharing information in the areas of delivery schedule, usage of purchased parts, quality, design, production process, and production activities are essential for JIT working partnerships. In this way, suppliers are able to coordinate their production planning processes with JIT manufacturers. By sharing information and being knowledgeable about each other's business, partners are able to act independently in maintaining the relationship over time" (Mohr and Spekman, 1994). Information sharing between buyers and suppliers is important to develop and maintain trust. Sharing this type of information requires trust between the firms. If distrust or conflict is present, open communication might convey coercive power, which leads to deleterious relationships (Mohr and Nevin, 1990). Empirical studies have shown that poor communication and feedback is one of the biggest barriers in JIT working

partnerships, and many JIT implementation problems can be overcome by improving communication between JIT suppliers and buyers (Celley et al., 1987; Lascelles and Dale, 1989).

5.3.3 The Economic Feasibility of Implementing EDI in a JIT Environment

The cost of setting up an EDI program can be substantial. The upfront expenses include the development, purchase or lease of hardware, protocol software, application and translation software, as well as, education and training costs. In addition, man-hours for evaluation and meetings can also be substantial. These can be offset, somewhat, by phased implementation, which can mitigate expenses. Operational costs stem from communications, maintenance and network charges. A cost/benefit analysis involved in evaluating an EDI investment requires that a company weigh the potential benefits and market factors against the costs of implementation and maintenance of a system. EDI requires that purchasing, sales, accounts receivable and payable, traffic, finance information systems, legal and auditing functions evaluate the cost-benefit equation separately. This requires a high level of executive commitment to the project, from the beginning. The executive must have a wide vision to see the workings of the various departments and the benefits to the entire company. When EDI is viewed from several functional areas, the start up costs can be distributed over several areas. At the same time, elevating EDI to a corporate level reduces duplicative efforts, improving implementation coordination and training. As an EDI program develops, communication and document content standards must be addressed.

Communications standards permit computers to talk to each other. To accomplish this, computers must send and receive data at the same rate of speed. Communications protocols enable computers to identify and speak with each other. Third party network services provide the ability to receive and send electronic documents between partners, even if they utilize different EDI formats.

5.3.4 The Benefits of Adopting EDI in a JIT Environment

One of the main tools that facilitate work under the environment of JIT partnership is Electronic Data Interchange. EDI must be viewed not just as a technological issue, because the technology is not new, but also as a business issue. A successful EDI program will improve the relationship between buyers and suppliers. Information must be precisely formatted to enable a computer to process information without human assistance. Determining this precise format requires extensive cooperation between trading partners and internal departments. The amount of mutual trust and cooperation between trading partners in developing a successful EDI program results in the development of true partnerships. Moreover, one of the driving forces behind the implementation of EDI is that it promises to reduce costs by improving efficiency, accuracy, and reducing time. Within the JIT partnership context, EDI offers many potential benefits, such as, an increase in the efficiency of managing inventory where it can be gained by reducing the inventory cost and the associated cost of carrying and storing inventory.

From the buyer's perspective, the ordering activities become more efficient since the transmission of order requests is faster and more accurate. For example, using automated transmission via EDI, instead of using (paper-based) labor-intensive transactions, can reduce of document-processing task times and related costs. Other benefits associated with the reduction of paper work are automatic reconciliation, reduced clerical workload and phone time, and automated ordering and verification. In the traditional course of business, paper-based systems have slowed communication, increased errors, and added costs. Improved order entry results in fewer personnel and errors, as well as a reduced need for equipment and facilities.

In addition, EDI can lead to a reduction in inventory levels by reducing the lead time and uncertainty during lead-time. Since communication between the buyer and supplier is faster and is sent through a more reliable and faster medium of electronic communication rather than alternate method there is a reduction in ordering costs, lead time, and the uncertainty of the actual arrival date. Therefore, gaining control over the transportation chain allows the total amount of inventory to be reduced. The orders can be placed in smaller quantities and more frequently.

Therefore, the improvement in time performance resulting from the uses of EDI can facilitate a movement toward JIT partnership. Moreover, implementing EDI in a JIT environment can reduce the transaction costs dramatically. Such reduction can be recognized in the ordering process, shipping, tracking, warehousing, spoilage and waste, stock outs, and excess inventory. The

benefits of implementing EDI from the buyer's perspective are summarized in Table 5.7.

From the supplier perspective, implementing EDI can enhance production scheduling and quality assurance as a result of reduction in lead-time and uncertainty during lead-time. These causes will decrease safety stock requirements, with an accompanying savings in freight and material costs. Companies that depend on customer service can develop a major competitive advantage with EDI. Customers find it easier to place and receive orders. In today's highly competitive business climate, the use of EDI results in even more important benefits. The benefits of implementing EDI from the supplier's perspective are summarized in Table 5.8.

Wal-Mart Inc., one of the largest discount retailers in the U.S., was able to offer a greater selection of goods in a fixed amount of floor space, since lower amounts of inventory could be carried. The checkout registers are directly linked to the Wal-Mart computer systems, so those sales can be summarized and transmitted to suppliers very quickly. When a sales quota in a store is met, an automatic replenishment order is generated and sent to the supplier or manufacturer. The reduction in lead-time directly led to lower inventories in the store (McCubbrey, 1992).

There are indirect benefits accrued from sharing information on anticipated demand, orders, and production schedules. These may include decreased safety stock requirements, with the accompanying savings in freight and material costs. Reduced inventory and labor costs result in improved cash flows. Also, ustomer satisfaction

increases due to improved information and quality of service and overtimes and indirect benefits will be substantially greater than direct benefits.

Table 5.7
The Effect of Using EDI on the Cost Activities from Buyer Prospective

Cost Activity	Effect of EDI on the Cost Activities	Justification
ORDERING COSTS (A_B)		
Ordering activities (issuing purchase orders, processing of invoices and preparing of payment.	Reduced	Transmission of order requests is faster and more accurate. Fewer personnel.
Inspecting the order	Reduced	Fewer errors as a result of less human intervention
Transportation	Reduced	Faster communication
HOLDING COSTS (r_B)		
Warehouse cost, insurance, taxes , spoilage, obsolescence, storage and handling cost, cost of capital, and opportunity cost	Reduced	Reduction in lead time and reduction of uncertainty during the lead time
STOCK OUT COSTS:		
Backorder Situation:		
Loss of future sales (customer inconvenience), cost of paper work to track the order, and emergency shipping costs.	Reduced	The uncertainty of the actual arrival date and time can be reduced.

Table 5.8
The Effect of Using EDI on the Cost Activities from Supplier Perspective

Cost Activity	Effect of EDI on the Cost Activities	Justification
SETUP COSTS (A_S)		
Maintenance cost connected to setup	Decreased	Enhance production scheduling and quality assurance as a result of reduction in lead-time and reduction in uncertainty during lead-time.
HOLDINGCOST (r_S)		
Warehouse cost, insurance, taxes, breakage, obsolescence, storage and handling cost, cost of capital, and opportunity cost.	Decreased	A result of reduction in lead-time and reduction in uncertainty during lead-time.

CHAPTER 6
SUMMARY AND CONCLUSIONS

6.1 Summary

JIT philosophy calls for frequent, small deliveries, which arrive on time, with the quantity and quality required. For JIT to be effective there should be a cooperative relationship between the buyer and the supplier. They should work together to enhance their competitive positions in the market place. This study extends the quantitative models published in the literature to provide more realistic models for JIT operations and evaluates the costs and benefits of JIT partnerships to help in the negotiation process between the partners. In this chapter, we first summarize the four most important modeling contributions of our study followed by a summary of the most important managerial contributions. Finally, we discuss the limitations and future research directions.

First, we provided a new model (Model 2, described in Section 3.4.2) for the optimization of the joint total relevant cost of the buyer and supplier in the typical JIT scenario where the buyer's order is delivered in multiple shipments and the supplier's production lot size is an integer multiple of the shipment size. We allow the number of shipments per buyer's order quantity to be different from the number of shipments per production lot size. This new extension is more realistic model that can provide more flexibility and cost saving by choosing the appropriate production lot size for the supplier. The new model, for a deterministic environment, determines the optimal values of the three decision variables, the shipment size q, the number of shipments of an order n, and the number of shipments per production lot size m.

Second, we provide a new model (in Section 3.3.1) to quantify the advantages and costs of maintaining flexible resources. The model shows the production cost increase that can be expected if dedicated resources cannot be applied due to increasing uncertainty in the customers' demand. Under JIT supply, ideally, the buyer and supplier operate in a deterministic environment, thus, neither the buyer nor the supplier has to hold safety stock. There is always uncertainty in the customer's demand, but flexible resources and short production and supply lead times enable the required service level to be met in this case without holding safety stock. In practice, however, the appropriate flexibility and capacity are not available or, as we show in our model, are too expensive to maintain.

To avoid the high cost of flexible resources, in several cases in practice either the buyer or the supplier holds safety stock to provide the appropriate customer service level. This is the stage of transition to real JIT supply. Only the case where the buyer is holding safety stock was examined previously. Our third contribution is Model 4 (Section 3.4.4) which considers the case where the supplier is holding safety stock. In the spirit of JIT, the study finds the minimum safety stock, under frequent small lot shipments, that is needed in order to protect against shortages that may be caused by delivery delays or excess demand. Our safety stock model provides a valid approximation without the knowledge of the distribution pattern of the random customer demand as long as the pattern of production follows the demand pattern according to the JIT supply agreement. The procedure, based on the new safety stock model, determines the optimal values of four decision variables jointly: the safety

stock of the supplier, the order quantity, the shipment size, and the number of shipments

One of the major problems associated with the application of JIT models is the lack of appropriate cost data in traditional accounting systems to quantify the costs and benefits of implementing a JIT partnership. Our fourth contribution is to provide appropriate accounting data. We specify the cost activities, cost drivers and traceable costs of the buyer and supplier using an Activity Based Costing System (ABC). Additionally, we explore the costs and benefits that are experienced through the exchange of information between the buyer and the supplier in a JIT environment.

In Section 2, the implications of the new models are summarized from a managerial point of view. Section 3 presents the limitations of our research and future research directions.

6.2 Managerial Implications of the New Models

Buyer-supplier cooperation is emphasized in JIT environments. Our models minimize the joint total relevant costs for the two parties in order to enhance this cooperation. Either party will have a lower total cost if their optimal policy is used rather the joint optimal policy. However, the joint optimal policy provides a joint total cost that is less than the sum of the individual total costs for any other policy including the ones where one party's optimal policy is used. This joint total cost improvement is considerable, it is typically in the range of 5% to 30%, thus, it provides a strong economic motivation for cooperation and price negotiation.

Extensive numerical and sensitivity analyses have been made to identify the cost parameters that have the most significant effect on the joint optimal solution. We find that the setup cost and inventory holding cost for the supplier are causing the highest incremental changes in the joint optimal value of the total relevant cost. The two cost parameters have an identical effect on the total relevant cost. The relationship between the cost increase and cost parameters is close to linear. The numerical results reveal that the inventory holding cost for the buyer and the selling price are the most influential cost parameters on the joint optimal shipment size. The two cost parameters have an almost identical effect on the shipment size. If we increase either one of them, the shipment size will decrease. The last results are published in previous research.

We suggest that these models can be used as quantitative tools to find the joint optimal policy and help in contract negotiations. The weaker party can encourage the other party to agree upon the joint optimal policy by offering compensation for the loss incurred by the stronger party by moving away from its individual optimal policy. This compensation can be in the form of a long-term contract, a price discount or increased unit price, or may be a premium paid to the other party. Our models can be used to estimate the fair amount of compensation necessary.

Cooperation and compromise with the joint optimal policy will always result in enhancing or equaling the previous cost position of both parties. Numerical examples imply that the buyer and the supplier receive considerable benefit from using the joint optimal policy rather than the optimal policy for the other party. The

benefit that the buyer can typically achieve is in the range of 5% to 75%, after compensating the supplier for its loss. The benefit that the supplier can typically achieve is in the range of 3% to 30%, after compensating the buyer for its loss. Therefore, we believe that these new models promote cooperation between the buyer and the supplier, which provides a better working relationship and considerable cost savings in a JIT environment.

The two most significant factors influencing the buyer's benefit are the production rate and demand rate. The buyers benefit is increasing with increase of the demand rate and with the decrease of the production rate. The supplier's benefit is influenced mostly by the supplier's setup cost and the buyer's ordering cost. The supplier benefit is increasing with the increase of the ordering cost and with the decrease of the setup cost.

We compare Model 1 with the new extension, Model 2. The new extension always has the lowest total optimal joint cost; however, the cost difference is not large in many cases. This can be the result of the low sensitivity to changes of the EOQ type order quantity models. The robust model results in small cost differences. For Model 2, the optimal number of deliveries is larger and the delivery size is smaller, and there is a larger saving for the party that accepts the move from its individual optimal policy to the joint optimum policy than with Model 1. In regards to comparisons between Model 3 with the new extension, Model 4, the results show that the total joint cost under Model 3 is smaller.

Our study shows the importance of timely and honest cost information exchange between the buyer and supplier in the JIT environment. It also

demonstrates the usefulness of technologies such as Electronic Data Interchange (EDI), which facilitate such communication.

In an Activity Based Costing system, the focus is on identifying and measuring the costs of activities that consume resources. Once the activities' costs are identified, the activities are traced to the products that caused the activities. Costs are then assigned to the products based on their share of the activities generated. To provide appropriate accounting data, we specify the cost activities, cost drivers and traceable costs of the buyer and supplier. More accurate product costs are the result of an ABC costing system. Therefore, the company is in a competitive position because it can determine more accurately its products' costs. Purchasing negotiators in cost analysis work can also use this development. Finally, cost control is also improved because costs are identified with the activities that incurred the costs. Better cost control is facilitated by the use of an ABC system. These factors can clearly lead to increased profitability and competitiveness.

6.3 Limitations and Future Research Directions

Given the importance and complexities of some of the issues involved in a JIT partnership, it is unlikely that a quantitative model can be developed that can consider all the possible variables. The relevant quantitative models, including our extensions of previous models, have several limitations and there are several other directions in which to extend the quantitative models and managerial investigations. Here, we try to summarize the most important limitations and future research directions.

The quantitative models of JIT cooperation, including our models, consider the connection of one buyer and one supplier. JIT typically promotes single sourcing. Still, in practice, several companies have multiple sourcing for a significant percent of their purchased items including Toyota and other pioneers of JIT. Multiple sourcing under JIT production is a very challenging extension possibility. Another possibility is the extension for multiple buyers of a single supplier or to a network of multiple-buyers and multiple-suppliers. Under JIT supply no such quantitative model has yet been published.

We consider only a single product. Connections among products may require the multiple product case. Price discounts, constraints on shipment size, or number of shipments were not considered in our study. Future research can consider these factors in a JIT environment.

We assumed a continuous review, fixed order quantity system where orders and shipment requests can always be issued. In certain situations, periodic policies may be used, but, JIT typically advocates continuous ordering and shipment policies. We considered equal shipment sizes. The effect of varying shipment sizes can also be investigated.

In the determination of the safety stock, we considered the probability of no stockout as a service measure. This service measure is appropriate in the case where the shortage cost is proportional to the number of shortages and doesn't depend on the length of the shortage. This is a valid assumption in a production environment where a stockout requires a changeover to a different product. In the wholesale or retail situation, this is also an appropriate assumption if an expedited shipment with a

fixed additional cost is necessary in case of a shortage. In these situations, the shortage cost usually does not depend on the length or quantity of shortage. In other cases of wholesale or retail, the shortage cost is proportional with the time or amount of the shortage. For these cases, different service measures like the expected amount or time short should be considered.

We showed the costs and benefits from applying an EDI system between the buyer and the supplier in the JIT environment. Future work can be done to capture the changes in the cost parameters due to the implementation of an EDI system and to determine how these changes affect the joint solution. A new challenge and excellent research area could be the evaluation of the effects of Internet connection and electronic commerce on the JIT partnership.

Beyond the monetary gain, there are several additional advantages of JIT partnership which are difficult to quantify, such as higher quality levels, more flexibility, faster problem resolution, reduced paperwork, and more efficient planning which will result from negotiation and cooperation. We believe that the quantitative effects of cooperation and negotiation should be combined with qualitative managerial considerations in making the final decision.

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APPENDIX A
NOTATION

A_B = total fixed cost of a purchase order

A_S = setup cost for the supplier (producer),

C_B = purchasing cost of a unit of the considered product for the buyer

C_P = the expected total unit cost of production, including unused production

C_S = variable cost of the finished product for the supplier

D = expected annual demand of the product considered

D_C = the fixed contracted annual demand

d_L = random variable representing demand during lead-time.

d_r = buyer's demand rate

D_R = random part of the annual demand, with expected value μ and standard deviation σ

$F(t)$ = cumulative demand of the customer up to time t where $0 \le t \le T$

$F^*(u)$ = normalized cumulative demand up to time u where $0 \le u \le 1$

$G_n(t)$ = cumulative amount to be delivered up to time t where $0 \le t \le T$

$G^*_n(u)$ = normalized cumulative amount delivered up to time u where $0 \le u \le 1$ and $Q = 1$

$H_k(t)$ = cumulative amount produced up to time t where $0 \le t \le T$

$H^*_k(u)$ = normalized cumulative amount produced up to time u where $0 \le u \le 1$ and $Q = 1$

k = number of setups per customer order (n/m)

K = safety factor that depends on the customer service level, α

L = known constant lead-time of the supply to the buyer

L_B = additional cost of losing flexibility per unit ordered but not delivered

m = the number of shipments per production lot size

M_B = the normalized safety stock held by the buyer

M_S = the normalized safety stock held by the supplier

n = the number of shipments of an order in a contract period

P = the annual production quantity (the actual annual sales volume)

p_r = production rate expressed on daily basis

P_α = the probability of no shortage in the contract period (0,T)

q = shipment size

Q_B = order size, or contract quantity, that is delivered in small shipments

Q_S = production lot size

r_B = inventory holding cost factor, the proportion of dollar value of the stock for the buyer

r_S = inventory holding cost factor, the proportion of dollar value of the stock for the supplier

r = inventory level at which order is placed (reorder point)

R_d = annual production capacity of dedicated production resources

R_f = annual production capacity of flexible production resources

S_B = the quantity of safety stock held by the buyer

S_S = the quantity of safety stock held by the supplier

TRC_B = total relevant cost for the buyer

TRC_J = joint total relevant cost for the buyer and the supplier

TRC_S = total relevant cost for the supplier

u = unit cost of unused dedicated production resources

v_d = unit production cost with dedicated resources

v_f = unit production cost with flexible resources

Z_B = receiving cost per shipment for the buyer

Z_S = supplier's costs related to each shipment to the customer

σ_D = standard deviation of demand

μ_L = average lead-time from the supplier to the buyer

μ_{LD} = average demand during the lead-time

σ_{LD} = standard deviation of the demand during the lead-time

σ_L = standard deviation of the lead-time

APPENDIX B
EFFECT OF REDUCTION IN UNCERTAINTY ON THE UNIT COST

Table B1
Effect of Decreasing Demand Uncertainty

D_C=	100	120	140	160	180	200	220	240	260	280	300
$D_R=\mu+k*\sigma=$	250	230	210	190	170	150	130	110	90	70	50
$R_d=D_C+\mu=$	150	170	190	210	230	250	270	290	310	330	350
$R_f=k*\sigma=$	200	180	160	140	120	100	80	60	40	20	0
	Rate of increase in expected unit production cost, V:										
Cost rates σ =	100	90	80	70	60	50	40	30	20	10	0
v_f/v_d=1.2 u/v_d=0.2 k=2	1.33	1.22	1.13	1.07	1.05	1.03	1.02	1.02	1.01	1.01	1.00
v_f/v_d=1.2, u/v_d=0.4 k=2	1.63	1.41	1.23	1.12	1.07	1.05	1.03	1.02	1.01	1.01	1.00
v_f/v_d=1.2, u/v_d=0.6 k=2	1.93	1.60	1.34	1.17	1.10	1.07	1.04	1.03	1.02	1.01	1.00
v_f/v_d=1.2 u/v_d=0.2 k=1.65	1.46	1.34	1.22	1.12	1.06	1.04	1.03	1.02	1.01	1.01	1.00
v_f/v_d=1.2 u/v_d=0.4 k=1.65	1.88	1.64	1.40	1.21	1.11	1.06	1.04	1.03	1.02	1.01	1.00
v_f/v_d=1.2 u/v_d=0.6 k=1.65	2.30	1.95	1.59	1.31	1.15	1.09	1.06	1.04	1.02	1.01	1.00

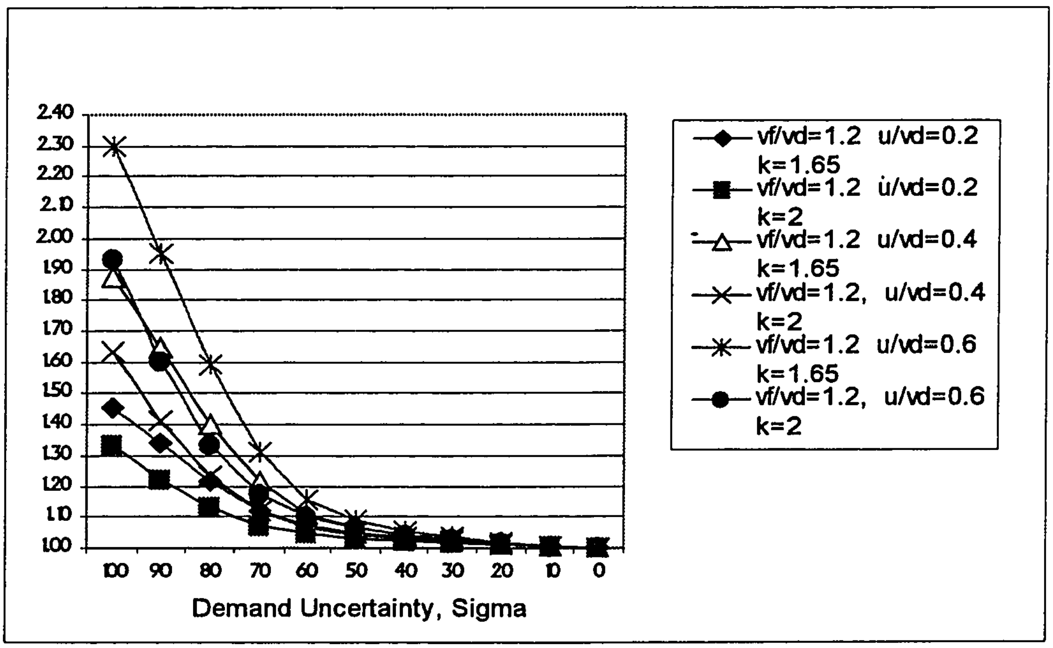

Figure B1
Rate of Increase in Expected Unit Production Cost, V:

Table B2
Effect of Decreasing Demand Uncertainty

D_C =	100	120	140	160	180	200	220	240	260	280	300
$D_R=\mu+k*\sigma=$	250	230	210	190	170	150	130	110	90	70	50
$R_d=D_C+\mu=$	150	170	190	210	230	250	270	290	310	330	350
$R_f=k*\sigma=$	200	180	160	140	120	100	80	60	40	20	0
	Rate of increase in expected unit production cost, V:										
Cost rates $\sigma=$	100	90	80	70	60	50	40	30	20	10	0
$v_f/v_d=1.2$ $u/v_d=0.2$	1.33	1.22	1.13	1.07	1.05	1.03	1.02	1.02	1.01	1.01	1.00
$v_f/v_d=1.2$, $u/v_d=0.4$	1.63	1.41	1.23	1.12	1.07	1.05	1.03	1.02	1.01	1.01	1.00
$v_f/v_d=1.2$, $u/v_d=0.6$	1.93	1.60	1.34	1.17	1.10	1.07	1.04	1.03	1.02	1.01	1.00
$v_f/v_d=1.5$ $u/v_d=0.2$	1.38	1.27	1.17	1.11	1.07	1.06	1.04	1.03	1.02	1.01	1.00
$v_f/v_d=1.5$, $u/v_d=0.4$	1.68	1.46	1.27	1.16	1.10	1.07	1.05	1.04	1.02	1.01	1.00
$v_f/v_d=1.5$, $u/v_d=0.6$	1.98	1.65	1.37	1.21	1.13	1.09	1.06	1.04	1.03	1.02	1.00

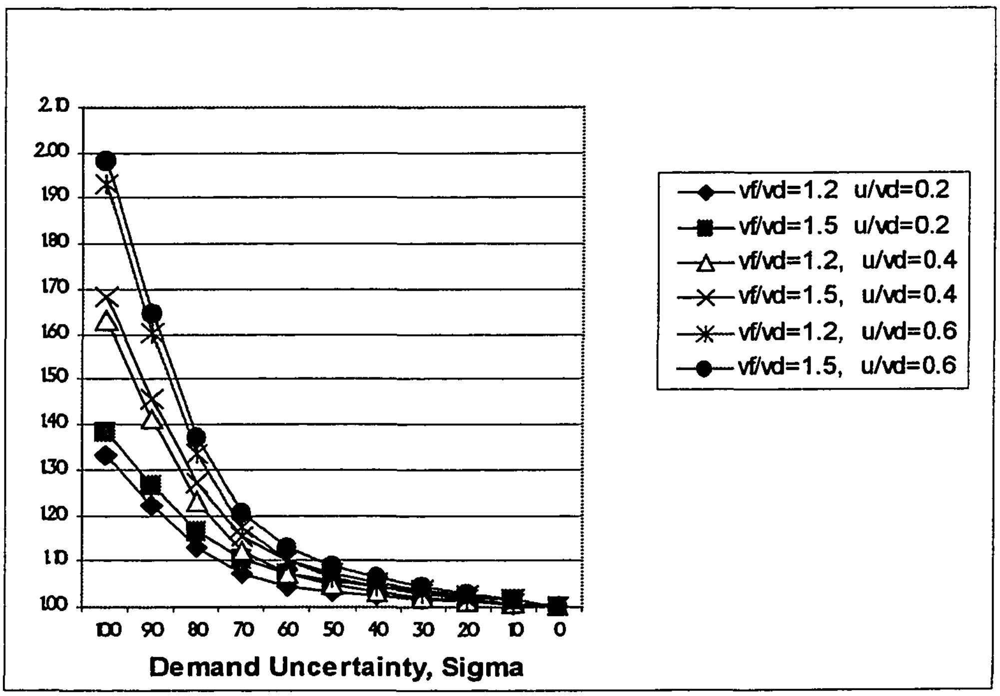

Figure B2
Rate of Increase in Expected Unit Production Cost, V:

VITA

Faisal B. Al-khateeb was born in Palestine, on September 17, 1964. He attended Yarmouk University, Jordan, earning the bachelor degree in Accounting with honor degree in 1987. In 1990, he earned the degree of Master of Business Administration from Tennessee State University, Nashville, Tennessee. In 1992, he earned the Master of Professional Accountancy from Louisiana Tech University, Ruston, Louisiana. He is currently a visiting professor at Grambling State University in Grambling, Louisiana. He has also served as instructor at Applied Science University, Amman, Jordan, during the period between 1992 to 1996. He is married with three children and will have a new baby in July 1999.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Faisal Badi Al-Khateeb

Major Field: Business Administration (ISDS)

Title of Dissertation: Quantitative Modeling and Information System Support for Just-In-Time Partnership

Approved:

Peter Kelle

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Robert Downer

Date of Examination:

12 May 1999