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JIT purchasing vs. EOQ with a price discount: An analytical comparison of inventory costs

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Abstract

The inventory costs of purchasing under economic order quantity (EOQ) model with a quantity discount is determined and compared to the costs under just-in-time (JIT). It is shown that at low levels of demand, JIT is the preferred method, whereas EOQ has the cost advantage for an item with a high demand. The model also predicts that the higher the value of the item, the carrying cost, or the ordering cost associated with the EOQ model, and the smaller the quantity discount rate, the wider will be the range of demand for which JIT remains preferable.

Keywords: JIT; EOQ; Price discount; Purchasing; Cost comparison

Nomenclature

D	annual demand for inventory item (units/year)
D_{ind}	indifference point; demand at which the total costs of EOQ and JIT are equal
$D_{\max}$	demand at which JIT's cost advantage is maximized
h	annual inventory holding cost per unit (\$/unit/year)
k	ordering cost (\$/order)
P	delivery (purchase) price of the inventory item (\$/unit)
P_E^0	Eq. 1
π	quantity discount rate
Q	order quantity
Q^*	optimum order quantity in the EOQ model
TC	total annual inventory costs (\$/year)
Z	cost difference between EOQ and JIT (\$)

Subscripts and superscripts

E	refers to the EOQ model
J	refers to the JIT model
max	maximum
min	minimum

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1. Introduction

An important decision facing a manufacturing company, whether it is a new entrant or an established manufacturer, is the choice of inventory management and control system. Two of the most popular inventory management techniques in use today are just-in-time (JIT) and economic order quantity (EOQ) model.

JIT is more than just an inventory management system since it is designed to virtually eliminate the need to hold items in inventory and, therefore, requires an overhaul of the entire production and supply system. The benefits associated with JIT include savings in inventory holding costs, savings in manufacturing costs, reduction in ordering costs, improved quality, elimination of waste, streamlining of the production process, and the elimination of production process bottlenecks [1]. A major component of JIT and an important factor in its successful implementation is JIT purchasing of parts, components, and raw materials [2–4].

Despite the impressive success of JIT programs and a plethora of literature prescribing it as the solution to many manufacturing ills, many companies still use the EOQ model to determine their purchase orders [5]. This is particularly true for small manufacturing firms who cannot effectively implement JIT purchasing [6]. Even companies that practice JIT do not purchase all of their supplies on a JIT basis. There are also some who believe that when EOQ is fully understood and carefully implemented its use can be quite effective, and yet there are others who argue that depending on the circumstances, and not always, one might be preferable to the other.

Johnson and Stice [7] state that the traditional inventory management practices that center around the EOQ model focus on minimizing the inventory costs rather than on minimizing the inventory. They argue that while these techniques may under-emphasize the costs of maintaining large inventories, JIT may under-emphasize the costs of not maintaining inventories, particularly, since such costs are often difficult to identify and measure. Jones [8] states that most manufacturers ignore some relevant and important costs associated with carrying inventory, and thus do not calculate EOQ lot sizes correctly. He argues that correct usage of EOQ model will result in lot sizes that closely approximate JIT lot sizes.

The successful application of JIT in many companies has generated a large body of literature advocating the use of JIT over EOQ. Zangwill [9], however, argues that what is needed is mathematical analysis and analytical modeling of JIT to scrutinize the validity of the descriptive results presented in the literature. Even though there are some studies that model and analytically compare different aspects of the two systems, in a 1993 review of JIT literature Gunasekaran et al. [10] concluded that JIT research has been primarily dealing with descriptive works, case studies, and surveys, making studies involving analytical modeling of JIT rather limited. The following is a summary of the findings of some of the available analytical studies.

In a comparison of the total costs of JIT purchasing and setup reduction with the costs under the Economic Production Quantity model, Hong et al. [11] report that JIT purchasing when combined with order splitting and investments in setup reduction could be cost effective. Ramasesh [12] recasts the EOQ model to quantify the cost of JIT purchasing and concludes that the ideal form of JIT purchasing; long-term commitments and sole sourcing, monitoring the supplier's quality during production, and small-size deliveries, would result in minimizing costs.

Baker et al. [13], however, argue that Ramasesh's model does not necessarily always lead to the ideal JIT purchasing of one unit at a time. Their model indicates that if the expected cost of negotiating a long-term contract with a JIT supplier is large in comparison to the contract quantity, EOQ purchasing may result in a lower cost. The model developed by Chyr et al. [14] also indicates that JIT and EOQ may be preferred under different conditions. They compare, for different setup times and damage rates, the costs of EOQ and JIT production and argue that only for certain damage rates and setup times, JIT production is more cost-effective than EOQ. In addition, in a recent study, Fazel [15] developed a mathematical model that compares the classical EOQ model with JIT purchasing and determines the point of cost indifference between the two systems.

Grant [16], while not recommending the use of EOQ as standard ordering policy, suggests that managers should consider the use of EOQ and price breaks in determining the order quantity even when they are operating in a JIT environment. Aggrawal and Dave [17] also present a model that recommends the optimal purchase decision in a JIT environment within the framework of an EOQ model with price discounts. Their model incorporates warehouse expansion costs, space allocation costs, and the possibility of defective and damaged items as well.

Wehrman [18] suggests that although the classical EOQ formula is very simplistic in its modeling of costs associated with purchasing and holding inventory, it has served a valuable role in giving purchasers a tool to roughly determine the most economic lot sizes. He recognizes the lack of a practical method for integrating price discounts in the analysis as one of the shortcomings of the EOQ model.

This paper complements the literature by presenting an analytical model to evaluate and compare the total purchasing and inventory costs associated with JIT and EOQ. It also expands the classical EOQ model to include a quantity discount scheme. The model will determine, for every item, the demand level at which the costs under the two systems are the same, and will also determine the level of demand where the cost advantage of the JIT system is maximized. In addition, the model can be used to examine the impact of different factors on the cost performance of the two systems. This will enable us to identify the conditions under which a company would be better off using one of these two models and to understand why for some manufacturers JIT may not actually lower the costs.

2. The model

Although all materials purchased by a company do not have a regular consumption pattern, the regularly consumed items generally account for most of the purchasing and inventory costs. For these items annual demand and consumption patterns can be determined in advance and used as the basis for negotiation with suppliers [19]. The EOQ model is more suited for determining the order size of such items. The EOQ model considered here also includes a price discounting scheme defined in Section 2.2.

2.1. EOQ assumptions

The model presented here utilizes the assumptions of the basic EOQ model. It is, therefore, assumed that ordering cost is fixed per order; holding cost for the inventory item is constant on a per unit basis; total carrying cost is linearly related to the average quantity held in inventory; and annual demand for the item is known and constant [20]. The latter assumption of the classical EOQ model is consistent with the one used by Jamal and Sarker [21] in developing an algorithm for finding the optimal batch sizes for manufacturing as well as purchasing raw materials in a JIT environment.

2.2. Price functions for EOQ

In EOQ purchasing, in practice, the delivery price of an inventory item is often a decreasing function of the order quantity since the cost incurred by suppliers is usually a decreasing function of the size of the delivery lot. To incorporate this reality, this paper considers a quantity discount function for the delivery price of the item under EOQ. The properties of this discount function are graphically shown in Fig. 1. It is assumed that for quantities below a certain level (Q_{max}) the delivery

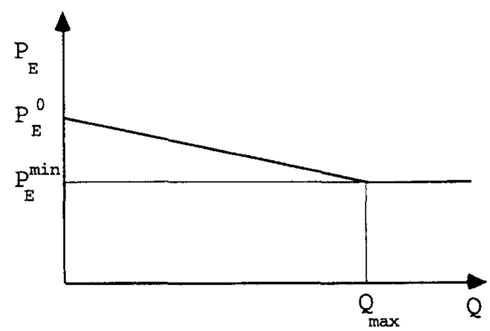

Fig. 1. EOQ price discount function.

price is a decreasing, continuous, and linear function of the order quantity. Beyond Q_{max}, however, the price stays at its minimum (P_E^{min}) which is the lowest price the supplier would charge no matter how large the order quantity is. This discounting scheme is an *all unit quantity discount* (i.e., the buyer pays the same unit price for every unit purchased) [22].

Mathematically the discount function is defined as follows:

$$P_E = P_E^0 \quad \text{for } Q = 0, \tag{1}$$

$$\frac{dP_E}{dQ} = -\pi_E \quad \text{for } Q \leqslant Q_{max} \tag{2}$$

$$P_E = P_E^{min} \quad \text{for } Q \geqslant Q_{max} \tag{3}$$

where P_E is the delivery price per unit, π_E is a constant representing the quantity discount rate (the rate at which the price of the item decreases with increase in order quantity), Q represents the order quantity of the inventory item, and P_E^{min} is the fixed delivery price when the order quantity exceeds a certain level (Q_{max}).

The initial condition for the first-order differential Eq. (2) is given by Eq. (1). Thus, the solution of Eq. (2) is given by

$$P_E = P_E^0 - \pi_E Q \quad \text{for } Q \leqslant Q_{max}, \tag{4}$$

where,

$$Q_{max} = \frac{P_E^0 - P_E^{min}}{\pi_E}. \tag{5}$$

2.3. JIT assumptions and price

Ideally, under the just-in-time philosophy some of the traditional costs associated with the EOQ model are either eliminated or substantially reduced. These costs include ordering, storage, cost of capital, insurance, and transportation costs. The supplier to a JIT buyer is strongly encouraged to implement JIT in its production facility to further reduce cost, improve quality, and become more responsive to the buyer. It is argued that it is to the economic advantage of a supplier to frequently deliver small quantities to JIT manufacturer as this would reduce the supplier's inventory cost [23, 24]. In this case, the supplier could pass some of these savings to the manufacturer by offering the items at a lower price. Under these ideal circumstances, the manufacturer will be economically better off to choose JIT over EOQ since JIT may result in a simultaneous reduction in purchase price, holding costs, and ordering costs.

The authors' observations of and experience with some major JIT companies, and some of the literature in the field, indicate that for many companies the reality is different from the ideal situation [25]. In practice, many suppliers of JIT manufacturers produce their products in large batches and respond to the JIT challenge by keeping large quantities of items in their inventories even though they may deliver them in very small quantities [3, 26, 27]. Quality control, inspection, and transportation arrangements will also become the responsibility of the JIT supplier, which if not properly managed could add to the supplier's costs. Thus in these cases, much of the inventory costs of the manufacturer is practically transferred to the supplier. Chapman [26] argues that "..a manufacturing facility will eventually pay for holding an inventory in the system regardless of where or why it is held. The only difference is in how the cost is accumulated and whether it is reflected in the customer's cost as inventory holding cost, purchase price, or transportation cost".

Therefore, it is reasonable to assume that, in the absence of a holistic system in which both suppliers and manufacturers operate under a perfect JIT system, the supplier would pass some of the costs to the JIT manufacturer in the form of higher item prices. That is, purchase price reflects the item cost as well as, at least partially, inventory ordering and holding costs. This translates into higher per unit purchase (delivery) price for the JIT manufacturer [28]. The analysis in this paper focuses on the scenario that manufacturer has to pay a somewhat higher price to buy an item on a JIT basis, compared to purchases made based on EOQ.

Under JIT, the price per unit over the course of a year or a contract may be negotiated based on the total quantity demanded during the year, but the price per unit will stay the same for each delivery. The per unit delivery price, therefore, is assumed to be a constant (P_J).

2.4. Cost functions and the optimum order quantity

For the EOQ model the total annual cost associated with inventory (TC_E) includes cost of delivered goods plus inventory ordering and carrying costs, and is given by:

TC_E = Annual ordering cost
+ Annual holding cost
+ Annual purchasing cost.

If the annual demand for the item is D and Q units are ordered every time, then kD/Q is the annual ordering cost, where k represents the cost of placing one order. The annual carrying cost is equal to $Qh/2$, where h is the annual inventory carrying costs per unit and $Q/2$ is the average inventory. The annual purchasing cost is the product of unit delivery price as given by Eqs. (4) or (3) and the annual demand (D). Therefore,

$$\mathrm{TC_E} = \frac{kD}{Q} + \frac{Qh}{2} + (P_E^0 - \pi_E Q)D \quad \text{for } Q \leqslant Q_{\max}, \tag{6}$$

$$\mathrm{TC_E} = \frac{kD}{Q} + \frac{Qh}{2} + (P_E^{\min})D \quad \text{for } Q \geqslant Q_{\max}. \tag{7}$$

In the EOQ model, it is assumed that for every possible level of demand, the manufacturer tries to minimize its cost by ordering a quantity which is equal to the optimum economic order quantity (Q^*); the quantity that minimizes the total annual inventory cost (TC_E). This value is obtained by differentiating the total cost function (Eq. 6) with respect to Q and setting it equal to zero, resulting in,

$$Q^* = \sqrt{\frac{2kD}{h - 2\pi_E D}}. \tag{8}$$

Note that Q^* is real only when $(h - 2\pi_E D) > 0$, and that it is the optimum order quantity only when $Q^* \leqslant Q_{\max}$. If Q^*, as obtained by Eq. (8), is greater than $Q_{\max}$, then it does not represent a feasible quantity for Eq. (6). For an order quantity above $Q_{\max}$ the price will be at a fixed level, $P_E^{\min}$. Therefore, the optimum order quantity (Q^{**}) is one that minimizes the sum of ordering and holding costs, and is given by the classical EOQ formula

$$Q^{**} = \sqrt{\frac{2kD}{h}}. \tag{9}$$

If $Q^{**} > Q_{\max}$ then Q^{**} is the optimum quantity. Otherwise, The total cost associated with an order quantity equal to Q^{**} should be calculated and compared with the total cost for an order quantity equal to $Q_{\max}$. The quantity that yields the lower cost is the optimum quantity. The optimum order quantity for the EOQ model, therefore, may be Q^* (Eq. 8), Q^{**} (Eq. 9), or $Q_{\max}$. The rest of the analysis in this paper focuses on the case where Q^* represents the optimum quantity ($Q^* \leqslant Q_{\max}$). Similar analysis may be conducted for the other two cases.

The total annual cost for the JIT system is the product of the unit price (P_J), which is assumed to be fixed, and the annual demand(D). Note that it is assumed that under JIT ordering and holding costs are either negligible, or transferred to suppliers and are thus reflected in the delivery price. The total annual cost under JIT is therefore,

$$\mathrm{TC_J} = P_J D. \tag{10}$$

2.5. The indifference point

The above equations provide for the determination of the total cost as a function of demand. It is expected that there exists a demand level at which the costs are the same under JIT and EOQ. This demand level is referred to as the indifference point.

Let Z represent the difference between the total costs of EOQ and JIT, then,

$$Z = \mathrm{TC_E} - \mathrm{TC_J}. \tag{11}$$

Substituting Eqs. (6) and (10) into the above equation results in

$$Z = \frac{kD}{Q} + \frac{Qh}{2} + (P_E^0 - \pi_E Q)D - P_J D. \tag{12}$$

Substituting Eq. (8) for Q yields the following cost-difference function:

$$Z = kD\sqrt{\frac{h - 2\pi_E D}{2kD}} + \frac{h}{2}\sqrt{\frac{2kD}{h - 2\pi_E D}} + \left(P_E^0 - \pi_E\sqrt{\frac{2kD}{h - 2\pi_E D}}\right)D - P_J D. \tag{13}$$

Note that Z is real only when $(h - 2\pi_E D) > 0$.

The cost-indifference point (D_{ind}) which is the level of demand for which the total cost of EOQ and JIT become equal is obtained by setting $Z = 0$ and solving for D, yielding:

$$D_{ind} = \frac{2kh}{(P_J - P_E^0)^2 + 4k\pi_E}. \quad (14)$$

Note that Z is also equal to zero when demand is zero.

2.6. Maximum cost advantage

The cost difference between EOQ and JIT is maximized for a demand level (D_{max}) at which,

$$\frac{dZ}{dD} = 0. \quad (15)$$

Solving Eq. (15) for D_{max}, yields the following:

$$D_{max} = \frac{h}{4\pi_E}\left[1 - \frac{P_J - P_E^0}{\sqrt{(P_J - P_E^0)^2 + 4k\pi_E}}\right]. \quad (16)$$

3. Discussion of results

Analysis of Eq. (13) indicates that JIT is the less costly alternative when the level of annual demand for the inventory item is lower than the indifference point, D_{ind}. As demand increases beyond this point, EOQ becomes less costly and, therefore, is the preferred method for controlling inventory orders. Further examination of Eqs. (13) and (14) provides more insight into the impact of different factors on the break-even point between the two inventory management systems.

Eq. (14) indicates that the break-even demand is a function of delivery prices under EOQ and JIT, inventory ordering and holding costs, and the quantity discount rate offered for EOQ purchasing. Rearranging Eq. (14) results in

$$\frac{D_{ind}}{h} = \frac{2}{(P_J - P_E^0)^2/k + 4\pi_E},$$

which is plotted in Fig. 2 for different values of π_E (discount rate). Note that the curve corresponding to $\pi_E = 0$ represents the classical EOQ model with no quantity discount. Each curve in Fig. 2 gives the values of D_{ind}/h for different values of the parameters $(P_J - P_E^0)/\sqrt{k}$. For a given value of π_E, the region to the right and above the curve represents the region in which EOQ is the less costly alternative and the region below and to the left of the curve represents the area where JIT is the preferred method. Fig. 2 indicates that, as expected, the

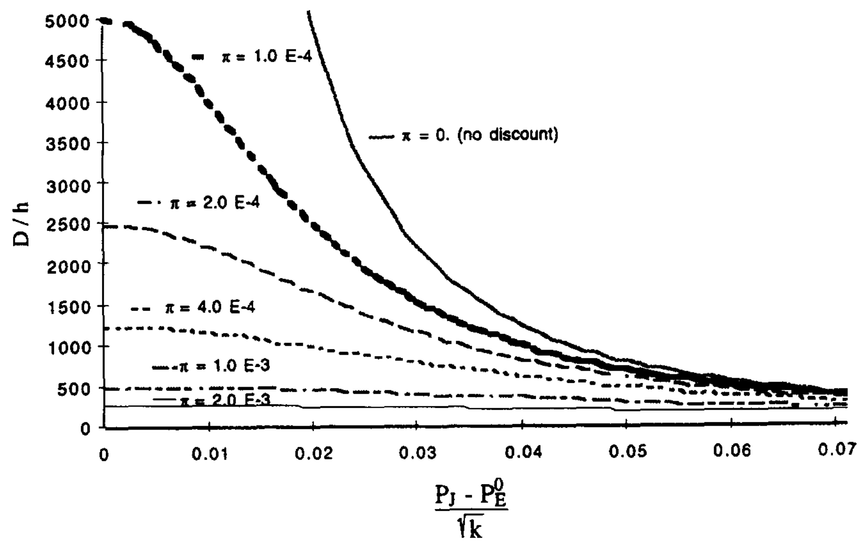

Fig. 2. Indifference curves for different discount rates.

higher the discount rate, the lower the indifference point (i.e., EOQ will have a cost advantage even for lower levels of demand).

Also as can be seen from Fig. 2, an increase in k decreases the abscissa which leads to an increase in D_{ind} for a given discount rate. This implies that an increase in EOQ ordering cost, ceteris paribus, will make JIT attractive for a wider demand range. It can also be seen that an increase in holding costs will reduce the ordinate, making JIT the preferred method for a wider range of demands. This confirms the expectation that when inventory holding cost is high the JIT system will become even more attractive. It is also important to note that for all values of the discount rate all the curves merge together at large values of the parameter $(P_J - P_E^0)/\sqrt{k}$, making EOQ the preferred method. This occurs at very low values of ordering cost or high price premium for JIT purchasing.

In summary, the model presented above predicts that the JIT method will be preferred for inventory items with lower levels of demand, or higher holding cost, or higher ordering cost. The EOQ method becomes more attractive as demand or quantity discount rate increase, or the holding cost, or ordering cost decrease.

3.1. An example

The preceding analysis is further illustrated by means of an example. Let us assume a manufacturer is considering a choice between EOQ and JIT for purchasing a given item with an annual demand level of 10,000 units. Purchasing the item on a JIT basis will cost him \$50.50/unit. If he purchases the item according to the EOQ model, the pricing strategy offered by the supplier will be as follows: The delivery price starts at \$50/unit. For every additional unit ordered, price will decrease by \$0.0004/unit for the entire order lot. The discount is valid for order quantities up to 2,500 units, when the price per unit becomes \$49. Beyond this level, the price remains the same. The estimated annual holding cost per unit is \$15 (about 30% of the purchase price), and ordering cost is \$60 per order. That is, $P_J = \$50.50$/unit, $P_E^0 = \$50$/unit,

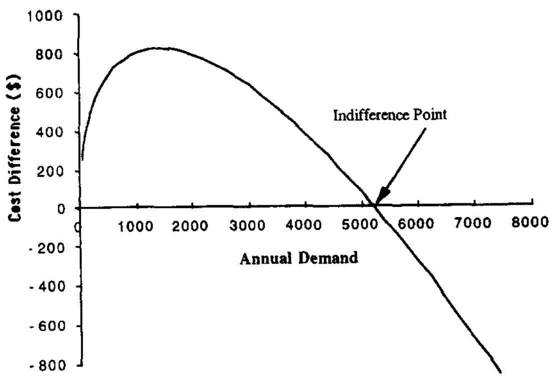

Fig. 3. Cost difference between EOQ and JIT.

$\pi_E = 0.0004$, $Q_{max} = 2\,500$ units, $P_E^{min} = \$49$/unit, $h = \$15$/unit/year, and $k = \$60$/order.

In order to assess which system is preferable we can use Fig. 2. For the conditions specified, $D/h = 666.7$ and $(P_J - P_E^0)/\sqrt{k} = 0.0645$. As can be seen in this Figure, the point (0.0645, 666.7) is clearly above and to the right-hand side of the curve corresponding to $\pi_E = 0.0004$, implying that EOQ is the less costly alternative for this item.

A more detailed analysis can be performed by examination of Eq. (13). Fig. 3 is a graphical representation of this equation and shows the cost difference between EOQ and JIT as a function of annual demand. It indicates that for low levels of demand JIT is more economical. As demand increases, the cost difference widens rapidly until a point where this difference is at its maximum (D_{max}). For this set of parameters, this quantity is 1406 units. As the annual demand increases beyond this point, the cost advantage of JIT begins to fade, until the two costs become equal at a demand level of 5202 units (the indifference point). For annual demand above this level (such as 10 000 units), EOQ is the more cost effective alternative.

4. Conclusions

In this paper, a mathematical model has been developed to compare the total annual cost for JIT and EOQ purchasing. The study finds the indifference point between the two systems (level of demand at which the costs are the same), and identifies under what conditions one system is superior to the other, from a cost perspective. The results indicate that the choice of the most appropriate system depends on many parameters.

The break-even demand is a function of EOQ and JIT delivery prices, inventory holding and ordering costs, and the discount rate for EOQ purchases. The analysis of the indifference point formula indicates that EOQ can be expected to remain competitive for items with higher levels of demand. Also, the lower the carrying cost, or the ordering cost associated with the EOQ model, or the deeper the quantity discount offered by the EOQ supplier, the lower will be the point of indifference between the JIT and EOQ models. This would make EOQ the preferred method for a wider range of demand. JIT, however, gains in competitiveness as the holding cost, or ordering cost increase, or demand for the inventory item decreases.

These results may provide a theoretical understanding of why and under what circumstances, despite all the expectations and anticipation created around it, JIT may not always lead to superior cost performance, and may explain in part the mixed enthusiasm and success among manufacturers in the application of the JIT system. Since inventory parameters vary from one product to another, the most suitable inventory control regime in a given manufacturing environment may actually be a combination of both systems. In fact, a mixed approach is a common practice among many manufacturing facilities in which some of their inventory items are controlled by JIT and some others by EOQ.

It should be noted that these results are based on the analysis of direct inventory costs associated with the two inventory systems, for a specific price discounting scheme. Some commonly practiced discounting methods are best defined by a step function. Conducting a cost analysis for such a case will be of significant practical value. In addition, proper implementation of JIT results in more than mere savings in inventory costs. Therefore, the decision to implement a JIT system may be advisable even though inventory cost considerations, per se, may not justify the choice. Before a final choice is made between EOQ and JIT, other factors such as quality and flexibility of operations under each inventory system must be considered as well.

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