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Partnership and negotiation support by joint optimal ordering/setup policies for JIT

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Abstract

Several studies have focused on the qualitative aspects of establishing and negotiating buyer–supplier partnerships, including Just-In-Time (JIT) supply, but few quantitative models and investigations are available in this area. We explore the two typical cases: supplier's dominance, with large production lot sizes and shipment sizes and buyer's dominance with small, frequent shipments. In each case, we compare the optimal shipment policy of the dominant party to the joint optimal policy. The savings or loss for each party and the total system cost improvements are computed which provide the quantitative support for negotiation, compromise, and compensation.

We extend the quantitative results for different JIT scenarios. We assume that the buyer's order is delivered in n shipments of size q. 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 before. This extension can result in substantial savings. We analyze under which circumstances does the saving warrant the more complex setup policy and in which cases is a simpler policy's cost close to optimum.

Keywords: Supply chain; Optimization; JIT; Inventory

1. Introduction and literature review

Several studies have focused on the qualitative aspects of establishing and negotiating buyer–supplier partnerships, including Just-In-Time (JIT) supply (Akacum and Dale, 1995; Burton, 1988; Ellram, 1991; Gilbert et al. 1994; Jap, 1999, Newman, 1988, O'Neal, 1987; Richeson et al. 1995). While, reviewing the literature and managerial practices, very few quantitative models and investigations are available in this area. Pan and Liao (1989) developed a simple Economic Order Quantity (EOQ) type model for a JIT supply system, where the order is delivered in n shipments. Ramasesh (1990) extended this model by adding a shipping cost to the total relevant cost. These models consider multiple deliveries of an order, but they only consider the purchaser's costs and no cooperation between the buyer and the supplier which should be emphasized in JIT purchasing. Banerjee (1986) developed a model to find the joint order quantity for the purchaser and the vendor

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in order to facilitate cooperation. He assumes that the order quantity is delivered in one shipment, however, JIT supply emphasizes multiple shipments. Goyal (1988) allows for production in lot sizes of nQ, where Q is the buyer's order quantity and n is an integer. Golhar and Sarker (1992) have also found that the total cost for the producer and purchaser decreases in most cases with reduced shipment sizes. Goh and Hum (1991) provide savings cost bounds for parties approaching JIT supply. Aderohunmu et al. (1995) examined a JIT cooperative 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 cooperation model. Fazel (1997) developed a mathematical model to compare JIT and EOQ. Kim and Ha (1998) examine lot—splitting over a finite planning horizon. Kelle and Miller (1998) apply quantitative tools for buyer–supplier negotiation in JIT purchasing.

In Section 2, we extend the above results for different JIT scenarios. First, we provide the quantitative models and illustrate them with a numerical example. JIT requires small, frequent shipments. We assume that the buyer's order, 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. This extension can result in substantial savings.

We describe the quantitative advantages and potential losses due to JIT supply, both from the buyers' and the suppliers' perspective. We show the amount of loss that results for the supplier from accepting the optimal JIT shipment policy of the buyer, compared to the cost of its optimal setup/shipment policy. In the same way, we quantify the cost increase for the buyer if the supplier's optimal shipment policy is enforced. First, we present a base-case numerical illustration, and then we discuss the dependence of the loss on different cost parameters, in which cases a large loss is expected and when is the loss smaller.

For the joint optimal policy, we summarize the dependence of the total system cost savings on the different cost parameters; in which cases a large savings is expected for the buyer and/or for the supplier if the two partners accept the joint optimal shipment policy, and when the savings is smaller. We analyze under which circumstances does the savings warrant a more complex ordering/setup policy and in which cases a simpler policy's cost is closer to optimum.

Section 3 summarizes the implications of improved and extended quantitative models in supply chain optimization on negotiation for managers of companies in Just-in-Time (JIT) buyer–supplier partnership. We conclude the paper with the limitation and extension possibilities of our research.

2. Quantitative modeling and numerical illustration

We illustrate the results in a numerical example. For the sake of comparison, we are going to use the following parameter and cost values as a base-case:

The buyer's demand and cost parameters are

D	1000 units/year,
A_B	\$225/order is the buyer's ordering cost,
C_B	\$20/unit is the selling price,
r_B	0.2 is the buyer's annual inventory carrying cost rate,
Z_B	\$1/shipment is the receiving cost for the buyer, the fixed cost of receiving a shipment,
L_B	0.03 is the cost rate of losing flexibility for the buyer (explained later in Section 2.1).

The supplier's production and cost parameters are

p	2500 units/year (the production rate, p, is 2.5 times larger than demand rate, d),
A_S	\$100/setup is the supplier's fixed setup cost,
C_S	\$10/unit is the production cost,
r_S	0.18 is the supplier's annual inventory carrying cost rate,
Z_S	\$4.5/shipment is the supplier's fixed cost related to each shipment to buyer.

The JIT partners can decide on:

Q_B quantity of the contract (buyer's order),
n number of shipments in a contract (order),
Q_S lot size of the supplier.

Yielding:

q average shipment size ($q = Q_B/n$),
m number of shipments per lot size ($m = Q_S/q$).

2.1. Optimal JIT policy for the buyer and its effect on the supplier's cost

The buyer in JIT supply requires small, frequent shipments. We assume that the buyer's order (contract quantity), Q_B, is delivered in n shipments of size $q = Q_B/n$. Previous quantitative models consider three relevant cost factors for the buyer, the ordering cost the inventory holding cost, and the receiving cost of each shipment which contains all the fixed overhead costs that are independent of the size of the shipment.

$$\mathrm{TRC_B}(q,n) = A_B D/(nq) + r_B C_B q/2 + Z_B D/q. \quad (1)$$

Under these cost considerations, the larger the contract quantity, Q_B, and the larger the number of shipments, n, the smaller the buyer's annual total relevant cost. The optimal shipment size, $q = Q_B/n$, slowly decreases with the increase of Q_B and n. The cost improvement is marginally decreasing with the increase of Q_B and the disadvantages of a very large contract quantity will offset the cost improvement.

The disadvantages of a very large contract quantity are not quantified in previous models, however, the loss of flexibility, and concerns of product changes and long commitments can result in a high risk that may outweigh the annual saving in ordering cost. To quantify the risk, we introduce a new cost parameter that will represent the managerial concern of having a very large order quantity. We assume that the part of the contract quantity that is not delivered to the buyer is a commitment that must be fulfilled in the future by buying the remaining contracted quantity. This commitment results in a loss of the flexibility to switch to another supplier or a different product. Although, it is a small disadvantage compared to other costs, still, it is important if very long commitments are considered. We propose a new cost parameter, denoted by L_B, which is the fourth cost factor: the cost rate of losing flexibility per unit dollar amount contracted but not yet received. In our numerical illustration, it is 3% of the committed contract value.

The total relevant cost of the buyer for ordering, inventory holding, receiving the shipments, and losing flexibility (as a consequence of undelivered, but committed contract) can be expressed consequently as

$$\mathrm{TRC_B}(q,n) = A_B D/(nq) + r_B C_B q/2 + Z_B D/q + L_B C_B (nq)/2, \quad (2)$$

or, in a short form,

$$\mathrm{TRC_B}(q,n) = \frac{x_B(n)}{q} + q y_B(n) \quad (3)$$

with notation

$$x_B(n) = D\left(\frac{A_B}{n} + Z_B\right) \quad \text{and}$$
$$y_B(n) = \frac{r_B C_B + L_B C_B n}{2}. \quad (4)$$

For a given n, we can express the optimal value of the shipment size for the buyer, by taking the derivative of the cost function (3) with respect to q, and setting it equal to 0. It yields the following expression:

$$q_B^*(n) = \sqrt{x_B(n)/y_B(n)}. \quad (5)$$

Substituting $q_B^*(n)$ in the cost function (3) provides the minimal joint total cost as a function of n:

$$\mathrm{TRC_B}(n) = 2\sqrt{x_B(n) y_B(n)}. \quad (6)$$

Relaxing the integer requirement on n, we can find the optimal n by taking the derivative of the function $x_B(n)\, y_B(n)$ with respect to n, and setting it equal to 0. It yields the following expression:

$$n^* = \sqrt{\frac{A_B r_B}{Z_B L_B}}. \quad (7)$$

The optimal n is the closest integer to n^* and the optimal q_B for the buyer is expressed in (5) using the values in (4) with the optimal n substituted. The optimal contract (order) quantity for the buyer is $Q_B = n q_B$.

If the buyer is strong and forces its optimal shipment size and frequency on the supplier, the supplier can choose its economic lot size as an integer multiple of the shipment quantity, $Q_S = mq_B$. The best value of m for the supplier is expressed in the next section. The numerical results for our base-case example are in the first column of Table 1. The results show that the supplier's cost increase, due to the enforced shipment policy by the strong buyer, is \$274 per year, that is a 71% loss compared to the optimal policy of the supplier. The optimal policy of the supplier is discussed in the next section.

Our numerical analysis revealed that as the supplier's shipment cost factor (Z_S) and the production rate increase the loss for the supplier compared to the cost of its optimal policy increases. Also, the larger the buyer's inventory carrying cost rate (r_B) and the selling price relative to the production cost (C_B/C_S), the larger the loss for supplier. The supplier's loss decreases with the increase of the setup cost (A_S), and also decreases with the decrease of the demand rate or with the increase of the supplier's inventory carrying cost rate (r_S). The A_B (buyer's ordering cost) and L_B (cost rate of the buyer for losing flexibility) parameters have a small effect on supplier's loss. Table 2 illustrates how a 50% increase or decrease in the base-case parameter values affects the supplier's percent loss relative to its optimal policy. For the typical ranges of the cost parameters, the supplier's cost increase relative to its optimal cost is very high, it is in the range of 45% to 166%.

2.2. Optimal JIT policy for the supplier and its effect on the buyer's cost

The total relevant cost of the supplier for setup, inventory holding (see Joglekar, 1988), and shipments can be expressed consequently as

$$\mathrm{TRC_S}(q,m) = A_S\frac{D}{mq} + r_S C_S \frac{mq}{2}\left[1 - \frac{d}{p} - \frac{1}{m} + \frac{2d}{mp}\right] + Z_S\frac{D}{q}, \tag{8}$$

or, in short form,

$$\mathrm{TRC_S}(q,m) = \frac{x_S(m)}{q} + y_S(m)q \tag{9}$$

with notation:

$$x_S(m) = D\left(\frac{A_S}{m} + Z_S\right) \quad \text{and}$$

$$y_S(m) = r_S C_S \frac{m}{2}\left[1 - \frac{d}{p} - \frac{1}{m} + \frac{2d}{mp}\right]. \tag{10}$$

For a given m, we can express the supplier's optimal value of q_S as

$$q_S^*(m) = \sqrt{x_S(m)/y_S(m)}. \tag{11}$$

For the optimal m, there are two cases, depending on the relation of production rate to demand rate.

Table 1
Optimal ordering policies and relevant costs using the base-case parameters

Policy	Buyer's optimum	Supplier's optimum	Joint optimum
Shipment size, q	22.4	539	47
No. of shipments per order, n	39	2	18
Order quantity, $Q_B = nq$	872.1	1077.5	847.9
No. of shipments per lot, m	19	1	10
Production lot size $Q_S = mq$	424.9	538.8	471.0
Buyer's total cost, $\mathrm{TRC_B}$	609	1611.5	635.2
Buyer's loss	0	1002 (165%)	26.1 (4.3%)
Supplier's total cost, $\mathrm{TRC_S}$	662.0	387.9	553.7
Supplier's loss	274 (71%)	0	166 (42.7%)
Overall joint total cost, JTRC	1271	1999	1189
Total system loss	82.2 (6.9%)	810.5 (68%)	0

Table 2
Effect of parameter changes on the supplier's loss

Parameter change	Supplier's percent loss (base case = 71%)								
	A_S	A_B	$r_B C_B$	$r_S C_S$	Z_B	Z_S	L_B	p	d
+50%	65%	71%	85%	63%	71%	92%	71%	114%	46%
−50%	94%	71%	62%	100%	100%	49%	71%	45%	166%

(a). In the case of $p<2d$, the optimal m is the closest integer to

$$m' = \sqrt{\frac{A_S(2d-p)}{Z_S(p-d)}} \tag{12}$$

and the optimal shipment size for the supplier, q_S , is expressed in (11) using the values in (10) with substituting the optimal m. The optimal setup quantity for the supplier is $Q_S = mq_S$.

(b). In the case of $2d<p$ the optimum is $m=1$. For his case, the optimal shipment (and lot size) for the supplier is

$$q_S^* = \sqrt{\frac{2D(A_S+Z_S)}{r_S C_S d/p}}. \tag{13}$$

If the buyer is strong and forces its optimal shipment size and frequency on the supplier, the supplier can choose its economic lot size as an integer multiple of the shipment quantity, $Q_S = mq_B$, with the integer m closest to

$$m' = \frac{1}{q_B}\sqrt{\frac{2A_S D}{r_S C_S(1-d/p)}}. \tag{14}$$

This result was used to calculate the supplier's cost for the optimal buyer's policy in the third column of Table 1.

Minimizing the supplier's total relevant cost, we find that the optimal policy for the supplier in our base-case example is to have one delivery for one setup ($m=1$) as we may anticipate. This property, however, is true only if the demand rate is less than half of the production rate (for $2d<p$). The optimal policy for the supplier is to have a large lot size and shipment size, as shown in the second column of Table 1.

If the shipment quantity is fixed by the supplier as $q = q_S$, the best order quantity of the buyer is $Q_B = nq_S$, with the integer n closest to

$$n^* = \frac{1}{q_S}\sqrt{\frac{2A_B D}{L_B C_B}}. \tag{15}$$

The buyer's cost will increase considerably compared to its optimal shipment policy described in the previous section. As we see from the third column of Table 1, accepting the best delivery policy of the supplier, in our base-case example, will increase the annual costs for the buyer by \$1002, that is a 165% loss compared to the buyer's optimal cost.

Our numerical analysis revealed that the larger the buyer's inventory carrying cost rate (r_B), the larger the loss for the buyer compared to the cost of its optimal policy. Similarly, with the increase of the selling price relative to the production cost (C_B/C_S), or with the increase of the production rate (relative to the demand rate), the buyer's cost increases. Also, the larger the setup cost (A_S), the larger the loss for buyer. The buyer's loss decreases with the increase of the parameters A_B (buyer's ordering cost) and L_B (cost rate of the buyer for losing flexibility). The buyer's loss also decreases with the increase of the demand rate, or with the increase of the supplier's inventory carrying cost rate (r_S). The shipment cost rate (Z_S) has a small effect on buyer's loss. Table 3 illustrates how a 50% increase or decrease of the base-case parameter values affects the buyer's percentage loss relative to its optimal policy. For typical ranges of the cost parameters, the buyer's cost increase relative to its optimal cost is in the range of 40–280%.

The ultimate goal in the supply chain is to decrease the total system cost, for the supplier and buyer, jointly. We target this goal in the next section.

Table 3
Effect of parameter changes on the buyer's loss

Parameter change	Buyer's percentage loss (base case = 165%)								
	A_S	A_B	$r_B C_B$	$r_S C_S$	Z_B	Z_S	L_B	p	d
+50%	208%	134%	242%	130%	165%	166%	144%	201%	145%
−50%	114%	219%	84%	250%	176%	163%	217%	144%	250%

2.3. *The joint optimal ordering/setup policy*

If the two parties, the buyer and supplier, are ready to cooperate, they can agree upon the joint optimal shipment size q_J, and the buyer can choose $Q_B = nq_J$ as the order quantity and the supplier can choose $Q_S = mq_J$ as the lot size, where m and n are integers. The total system cost, which is the joint total relevant cost of the two parties, is

$$\mathrm{JTRC}(q,m,n) = \frac{x_J(m,n)}{q} + y_J(m,n)q \tag{16}$$

with the notation

$$x_J(m,n) = x_S(m) + x_B(n) \quad \text{and}$$
$$y_J(m,n) = y_S(m) + y_B(n) \tag{17}$$

using the supplier's and buyer's x and y values expressed in (4) and (10).

The optimal shipment quantity minimizing the joint total cost (16) can be expressed as a function of m and n:

$$q_J(m,n) = \sqrt{x_J(m,n)/y_J(m,n)} \tag{18}$$

and the optimal total cost as a function of m and n is

$$\mathrm{JTRC}_J(m,n) = 2\sqrt{x_J(m,n)y_J(m,n)}. \tag{19}$$

Relaxing the integer requirement on m and n, by taking the partial derivatives of the function $x_J(m,n)y_J(m,n)$ with respect to m and n, and setting both equal to 0, we can derive the following two equations for the optimal m and n values:

$$n^*(m) = \sqrt{\frac{U_1 + U_6 m}{U_3 + U_5/m}} \quad \text{and}$$

$$m^*(n) = \sqrt{\frac{U_2 + U_5 n}{U_4 + U_6/n}} \tag{20}$$

with notation

$$U_1 = DA_B\left[\frac{r_B C_B}{2} + \frac{r_S C_S}{2}\left(\frac{2d-p}{p}\right)\right],$$

$$U_2 = DA_S\left[\frac{r_B C_B}{2} + \frac{r_S C_S}{2}\left(\frac{2d-p}{p}\right)\right],$$

$$U_3 = \left[\frac{L_B C_B D(Z_B + Z_S)}{2}\right],$$

$$U_4 = \left[\frac{r_S C_S}{2p}\left(\frac{p-d}{p}\right)(D(Z_B + Z_S))\right],$$

$$U_5 = \frac{L_B C_B D A_S}{2}, \quad \text{and}$$

$$U_6 = \frac{r_S C_S D A_B (p-d)}{2p}.$$

Using the expressions in (20), we can find the joint optimal integer values of n and m by iteration. This way, the three decision variables, q, n, and m are optimized jointly. The optimal policy will minimize the total relevant cost for the joint system of supplier and buyer. The joint optimal policy and its cost and saving values are contained in the last column of Table 1.

We analyze how the different cost factors and other parameters of the buyer and supplier influence the savings in total system cost if the joint optimal policy is used instead of the optimal policy of the strong party, the supplier or buyer.

(a) If the *supplier is the strong partner* and its large shipment size policy is forced on the buyer, the total system cost for the two parties is much higher than the total system cost of using the joint optimal shipment policy. In our base-case numerical example, the cost increase is \$810.5 annually that is 68% loss in the total system cost of supplier and buyer. We have discovered the following tendencies in the cost savings. The larger the setup cost, the selling price, the buyer's inventory carrying factor, or the production rate, the larger the savings achieved by using the joint optimal policy. However, an increase in the ordering cost, the parameter L_B (cost rate of the buyer for losing flexibility), or the production cost, results in a decrease in the savings. The selling price vs. production cost (C_B/C_S) and the r_B/r_S rates have the largest effect on the savings. The shipment costs have a small effect on the cost improvement. Table 4 illustrates how a 50% increase or decrease of the base-case parameter values affects the total system cost improvement if the joint optimal policy is chosen instead of the supplier's optimal shipment policy. In the usual range of the parameters in practice, the improvement is typically in the percentage ranges of 8–92%.

If the *buyer is the strong partner* and it's frequent, small-size shipment policy is forced on the supplier the total system cost for the two parties is higher than the total system cost of using the joint optimal shipment policy. However, this difference is usually much smaller than the savings achieved compared to the supplier's optimal policy, because the joint optimal policy is close to the buyer's optimal policy of frequent, small shipments. This quantitative result also supports the advantage of JIT deliveries.

In our base-case numerical example, the total system cost improvement achieved by the joint optimal policy is \$82.2 annually, that is 6.9% compared to the total system cost when the optimal shipment policy of the buyer is forced. Our numerical analysis revealed that the larger the buyer's inventory carrying cost rate or selling price, the larger the cost improvement. On the other hand, with the increase of the A_S, A_B, r_S, C_S, L_B, and d factors, the cost savings is decreasing. The receiving versus shipment cost (Z_B/Z_S) and the r_B/r_S rates have the largest effect on the savings. Table 5 illustrates how a 50% increase or decrease of the base-case parameter values affects the total system cost improvement if the joint optimal policy is chosen instead of the buyer's optimal shipment policy. In the usual range of the parameters in practice, the improvement is typically in the range of 5–14%.

2.4. Comparison of the joint optimal policy with two simplified joint policies

We now analyze the savings compared to the two simple JIT policies used in the previous publications. We summarize the dependence of the total system cost savings on the different cost parameters; in which cases a large savings is expected for the buyer and/or for the supplier if the two partners accept the joint optimal shipment policy, and when the savings is smaller. We analyze under which circumstances does the

Table 4
Effect of parameter changes on the system cost improvement: joint optimal policy—compared to the supplier's optimal policy

Parameter change	Percent improvement in the total system cost (base case is 68%)										
	A_S	A_B	r_B	r_S	Z_B	Z_S	C_B	C_S	L_B	p	d
+50%	79.7%	61.9%	105%	45.7%	67.3%	64.6%	97%	34%	63%	87%	66%
−50%	50.5%	77.3%	30.4%	8.7%	69.7%	73.9%	34%	120%	77%	66%	87%

Table 5
Effect of parameter changes on the system cost improvement: joint optimal policy—compared to the buyer's optimal policy

Parameter change	Percent improvement in the total system cost (base case = 6.9%)										
	A_S	A_B	r_B	r_S	Z_B	Z_S	C_B	C_S	L_B	p	d
+50%	6.4%	6.6%	8.1%	6.6%	4.8%	12%	7.4%	6.3%	6.5%	7.6%	6.3%
−50%	7.9%	7.9%	5.8%	7.7%	12.9%	2.7%	6.3%	7.7%	7.9%	6.5%	7.6%

savings warrant a more complex ordering/setup policy and in which cases a simpler policy's cost is closer to optimum.

(a) A simple policy for the supplier is to make a new setup and produce a lot size equal to the shipment size whenever a shipment is due. This is the special case of $m = 1$ with our previous notation, that means that for each shipment a new setup is done. The optimal n is the closest integer to

$$n^* = \sqrt{\frac{2A_B r_S C_S d}{C_B(r_B + L_B)(A_S + Z_B + Z_S)p}}; \tag{21}$$

the optimal shipment size is

$$q_J^*(n) = \sqrt{\frac{x_J(n)}{y_J(n)}}, \tag{22}$$

where

$$x_J(n) = \frac{D}{n}A_B + D(A_S + Z_B + Z_S), \tag{23}$$

$$y_J(n) = \frac{C_B(r_B + L_B)n}{2} + \frac{r_S C_S d}{2p}. \tag{24}$$

The order quantity $Q_B = nq_J^*$, the lot size $Q_S = q_J^*$, and the joint total cost of buyer and supplier is

$$\text{JTRC}(n) = 2\sqrt{(x_J(n)y_J(n))}. \tag{25}$$

For our base-case numerical example, the results are in the third column of Table 6.

There is a very high cost increase compared to the optimal policy (in the range of 30–90%) in most situations, so this policy is not an appropriate replacement for the joint optimal policy. The only exception is if the setup cost of the supplier is very low compared to the cost of inventory carrying.

(b) Another simple policy is to set the lot size equal to the order quantity (see Kelle and Miller, 1998). This is the special case of $m = n$, with our previous notation, that means that the setup quantity is equal to the order quantity. In this case the joint optimal n can be calculated simply by taking the integer closest to

$$n^* = \sqrt{U/V}, \tag{26}$$

Table 6
Comparison of the optimal and the two simplified policies: (a) when lot size equal shipment size ($m = 1$) and (b) when lot size equals order quantity ($m = n$), using the base-case parameters

Policy	Optimal	(a) $m = 1$	(b) $m = n$
Number of shipment per lot size, m	10	1	14
Number of shipment per order, n	18	1	14
Shipment size, q	47	352.5	46
Order quantity, Q_B	847.9	352.5	643
Production lot size, Q_S	471	352.5	643
Buyer's total cost, TRC_B	635.2	1441.9	650
Supplier's total cost, TRC_S	553.7	387	586
Overall joint total cost, JTRC	1189	1830	1236
Total system loss	0	641 (54%)	47 (4%)

where

$$U = DA_B\left[\frac{r_B C_B}{2} + \frac{r_S C_S}{2}\left(\frac{2d - p}{p}\right)\right] + DA_S\left[\frac{r_B C_B}{2} + \frac{r_S C_S}{2}\left(\frac{2d - p}{p}\right)\right] \tag{27}$$

and

$$V = \left[\frac{L_B C_B D(Z_B + Z_S)}{2}\right] + \left[\frac{r_S C_S}{2p}\left(\frac{p - d}{p}\right)(D(Z_B + Z_S))\right]. \tag{28}$$

The joint optimal shipment size

$$q_J^*(n) = \sqrt{\frac{x_J(n)}{y_J(n)}} \tag{29}$$

where

$$x_J(n) = \frac{D}{n}A_B + \frac{D}{n}A_S + DZ_B + DZ_S \tag{30}$$

and

$$y_J(n) = \frac{r_B C_B + L_B C_B n}{2} + \frac{r_S C_S}{2}\left(n - \frac{nd}{p} - 1 + \frac{2d}{p}\right). \tag{31}$$

The order quantity and lot size $Q_B = Q_S = nq_J^*$, and the joint total cost of buyer and supplier

$$\mathrm{JTRC}(n) = 2\sqrt{(x_J(n)y_J(n))}. \quad (32)$$

For our base-case numerical example, the results are summarized in the last column of Table 6. Our numerical analysis revealed that the larger the inventory carrying cost factor, the ordering cost or the selling price, the larger is the loss using the simple policy instead of the optimal joint policy. On the other hand, with the increase of the production or demand rate, or the A_S, Z_B, and L_B factors, the loss is decreasing. The ordering versus setup cost (A_B/A_S) rate and the r_S, C_S and L_B rates have the largest effect on the loss while the Z_S and C_B factors have minor effect. Table 7 illustrates how a 50% increase or decrease of the base-case parameter values affects the percent cost penalty in the total system cost (loss) if the simple policy is chosen instead of the joint optimal shipment policy. In the usual range of the parameters in practice, the improvement is typically in the range of 1–10%. Thus, for large A_B, r_S, Z_S, C_B, C_S and small A_S, Z_B, L_B, p, and d parameter values usually the savings achieved warrants the more complex optimal ordering/setup policy. If the parameters values tend into the reverse direction, the simpler policy's cost is closer to optimum and the application of the more complex joint optimal policy may not be preferable considering the increased administrative costs.

3. Negotiation tools and potential benefits

The above quantitative models and numerical results can directly be applied in negotiations between supplier and buyer. Calculating the net win or loss provides the quantitative support for each party to agree in the shipment policy and compensation, price consensus, or premium quantity. We examine three different scenarios in negotiation, considering the above numerical example and then summarize our numerical results from the managerial point of view.

(a) If the *supplier is strong*, the buyer's total relevant cost in our base-case numerical example is \$830 (136.5%) more than the buyer's optimum cost. Thus, the buyer is willing to negotiate with the supplier for smaller shipments in order to minimize the loss that is incurred by using the supplier's large optimal lot size as the shipment quantity. The closer the buyer can get to its optimal shipment quantity, the more their inventory cost will decrease. At the same time, however, the supplier's costs will increase which must be compensated for 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 the decreased shipment size and can make an offer to the supplier.

The supplier can also calculate its cost increase, due to the smaller shipment size, based on its own cost factors, and accept the offer or negotiate higher compensation. The tools, provided in the previous section, enable both parties to evaluate the different tradeoffs. As we can see from Table 8, in each case there is a possibility of improvement in the total system cost by choosing a compromise. The best deal is the joint optimal shipment size 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 them and still have lower

Table 7
Effect of parameter changes on the total system cost: joint optimal policy—compared to policy (b) when lot size equals order quantity ($m = n$)

Parameter change	Percent cost penalty in the total system cost (base case = 4%)										
	A_S	A_B	r_B	r_S	Z_B	Z_S	C_B	C_S	L_B	p	d
+50%	2.6	5.1	4.4	5.9	4.3	4.2	2.5	5.9	2.5	1.4	2.3
−50%	8.0	1.4	3.9	1.1	4.4	3.3	1.3	1.1	8.1	9.4	5.1

total costs. In this example, the buyer would experience a 50.3% decrease in cost after compensating the supplier's loss (see Table 2). This cost improvement typically ranges from 25% to 60% depending on the cost factors and other parameters (see Table 8).

Note: The benefit for the buyer depends on the parameter combinations as it is in Table 4.

(b) Similarly, if the *buyer is stronger* than the supplier, the supplier may be willing to make some sort of concession, such as price discount, to the buyer to encourage the latter to accept a larger shipment size. The best deal is the joint optimum. Table 9 shows the compensation amount and the net gain of 12.4% that can be achieved by the supplier. It is much smaller than in the case of a strong buyer described previously (typically, the net gain is in the range of 1% to 30% depending on the parameters as will be provided in the numerical analysis). This quantitative result seems to indicate that the joint optimal policy is closer to the buyer's optimal policy in the case of JIT consideration (see Table 9).

Note: The benefit for the supplier depends on the parameter combinations as it is in Table 5.

(c) If the *buyer and supplier have equal power in negotiation*, and they are ready to share information, the joint optimal policy can be used as a compromise providing the lowest cost. The savings in total cost can be split between the two parties using our models for estimating the costs and savings for both parties. This promotes cooperation between the buyer and supplier and may encourage each party to improve. The joint optimal policy always provides a monetary benefit for one party, and with compensation, the other party will also benefit.

Table 8
From supplier's optimal policy to joint optimum

	Buyer's cost	Supplier's cost	Total cost
Supplier's optimum	1611	388	1999
Joint optimum	635	554	1189
Cost improvement	976	−166	810
Compensation	−166	166	0
Buyer's benefit	810 (50.3%)	0	810

Table 9
Moving from buyer's optimal policy to joint optimum

	Buyer's cost	Supplier's cost	Total cost
Buyer's optimum	609	662	1271
Joint optimum	635	554	1189
Cost improvement	−26	108	82
Compensation	26	−26	0
Supplier's benefit	0	82 (12.4%)	82

4. Conclusions

The buyer and the supplier can use the models developed in this paper as a quantitative tool in contract negotiation. The weaker party can encourage the other party to agree to the joint optimal policy by price correction or a premium. The model can be used to estimate the minimal compensation amount necessary and the maximal amount that is economic. The compromise between those two values will always result in both parties enhancing or equaling their previous cost position. There can be considerable improvement, especially when the supplier's strong position of large shipment sizes is modified toward JIT supply. Beyond the monetary gain, there are several additional advantages, which are difficult to quantify, such as higher quality levels, more flexibility, faster problem resolution, reduced paperwork, and more efficient planning that will result from JIT negotiation and cooperation.

Our study revealed that

- The joint optimal policy will always result in savings in the total system cost for the supply chain.
- The savings achieved by the weaker party by negotiating for the joint optimal policy rather than the other party's optimal policy will be in the range of
  1–30% for the supplier,
  25–60% for the buyer.
- The joint optimal policy is closer to the buyer's optimal JIT policy with small, frequent shipments than the supplier's optimal large shipments policy.

- The savings in total system cost resulting from the use of the joint optimal policy can be split between the two parties providing a potential benefit for both buyer and supplier.

We considered a single buyer and supplier to concentrate on the quantitative benefits and negotiation issues. Extensions to multiple buyers and suppliers are interesting for the emerging e-commerce challenge, but are very difficult to analyze quantitatively. Our models are conservative in estimating the total benefit because they don't consider many qualitative factors, such as, quality issues, access to technology, improved product design, and improved production efficiency and delivery, which can result from cooperation. The parties must be ready to share information and this openness can be a problem for some organizations. However, the trust gained from negotiating and the benefit received from the joint optimal shipment policy may resolve this issue.

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