



Dual sourced supply chains: the discount supplier option

Ram Ganeshan^{a,*}, John E. Tyworth^b, Yuanming Guo^c

^a*QAOM Department, University of Cincinnati, Cincinnati, OH 45209, USA*

^b*Department of Business Logistics, Penn State University, USA*

^c*Director of Acquisition, Advanta Corporation, USA*

Received 21 September 1995; received in revised form 13 February 1998; accepted 29 August 1998

Abstract

In this paper, we examine the dynamics of a supply chain that has the option of using two suppliers – one reliable, and the other unreliable. We characterize the unreliable supplier with long lead-time mean and variance. Although the use of the unreliable supplier might potentially warrant higher inventory and transportation costs, it is attractive because of the willingness of the supplier to provide a discount on the purchase price. We analyze the cost economics of two suppliers in a broader inventory-logistics framework, one that includes in-transit inventories and transportation costs. In this broader perspective, we provide a simple heuristic and sample exchange curves to determine: (i) if the order should be split between the suppliers; and (ii) if the order is split, the amount of discount and the fraction ordered to the secondary supplier to make order-splitting a worth-while policy. © 1999 Published by Elsevier Science Ltd. All rights reserved.

Keywords: Supplier selection; Inventory; Lead-time policy

1. Introduction

Every company needs a successful supplier program, especially since purchased material typically is the largest component of cost for many products (Cavinato, 1994). The last decade has seen a significant shift in the sourcing strategy of many firms – moving from the traditional concept of having many suppliers to rely largely one source. One motivation for this is the obvious benefits of reduced paperwork, better quality, and supply innovation (Sheridan, 1988). A single source also establishes closer contacts with the supplier, in some cases these contacts extend as far as synchronizing their production delivery schedules to reduce inventory.

* Corresponding author. Tel.: +1-513-556-7174; Fax: +1-513-556-5499; E-mail: ram.ganeshan@uc.edu; Web: <http://www.econqa.cba.uc.edu/~ganeshr/index.html>

All these well-intentioned programs, however, are not without problems. One obvious problem is the erosion of supply base for the buyer. Relying on one supplier is risky, and often might not produce the lowest costs for the product. Also, as Newman (1988) suggests, single sourcing may lead to loss of technological thrust, excess control, and lack of identity for the supplier. Additionally, a stream of research in the last decade has focused on how the use of multiple sources can reduce ‘effective’ transit or lead-times that can make dual or multiple sourcing policy an effective risk strategy and cost reducing one. Almost all these studies emphatically conclude that under stochastic conditions the use of two or more similar sources reduces safety stocks and therefore the total inventory-system costs. In this paper, we attempt to strike a balance between the use of just one supplier, and the perceived cost benefits of using several. Specifically, we assume that a firm is using a primary or a preferred supplier. This supplier is responsible for a majority of the firm’s orders. We characterize this supplier as being ‘reliable’, quantified by low lead-time (or response times) mean and variance. Additionally, we assume that the firm has an option of using a second supplier, who we characterize as being unreliable, quantified by high lead-time mean and variance. This supplier is attractive to the firm because he is willing to provide a price discount. The basic question we set out to answer in this framework is twofold. First, what level of discount does the second supplier need to provide to make order-splitting a worthwhile policy, and second, if attractive, what portion of the order needs to be placed with the second supplier.

We contribute to the dual sourcing literature in two important ways. First, a majority of studies (reviewed below) that have investigated the use of multiple suppliers have assumed that the sources are identical. Those who have considered different suppliers have not investigated the prevalent scenario of a relatively unreliable supplier providing a price discount. In this study, we will investigate the economics of a supplier providing a price discount, and the associated trade-off’s in dual sourcing. Second, almost all the dual/multiple sourcing studies guide inventory policy from a myopic view of an inventory system. In our analysis, we expand the inventory-system focus on a broader perspective that includes in-transit inventories and transportation costs. This broader perspective is critical, since splitting the order with the secondary supplier increases the transportation, and possibly the pipeline inventories. The supplier’s discount should therefore be large enough to offset these costs.

This paper is structured as follows. In Section 2, we highlight the relevant literature on order-splitting. In Section 3, we analyze the firm’s cost function when it uses its primary supplier, and provide solution procedures to find the optimal inventory policies for this single supplier. In Section 4 we analyze the cost function of the firm when both suppliers are used, and illustrate the corresponding solution procedure. In Section 5, we present a numerical example to illustrate our framework. We summarize our findings in Section 6.

2. Literature overview

One of the earliest papers in dual sourcing is attributed to Sculli and Wu (1981). They assumed two suppliers with identical and normally distributed lead-times, and derived expressions for the mean and variance of the first or ‘effective’ lead-time. Sculli and Shum (1990) extended this idea and showed that splitting an order between many suppliers, whose lead-times are normally

distributed, results in a decrease in the lead-time of the arrival of the first portion. Hayya et al. (1987) demonstrated the same result with the Gamma distribution through simulation experiments. Pan et al. (1991) showed the lead-time compression when the lead-times of the suppliers are uniform, exponential, or normal distributions. Guo and Ganeshan (1995) later extended this idea and illustrated how the lead-time compression of multiple sourcing can be used in a decision making scenario. Kelle and Silver (1990a) studied the impact of multiple sourcing in a reorder point system with normal or Poisson demand, and Weibull lead-times. Using an order-fill policy, they show that multiple sourcing warrants lesser amounts of safety stocks when compared to the equivalent single sourcing scenario. They later extend this study (Kelle and Silver, 1990b) with similar results to a stock-out control policy. More recently, Hill (1996) showed that the average stock levels will be smaller for the multiple sourcing scenario, for both the order-fill and stock-out policies under any generic lead-time distribution.

Meanwhile, a parallel stream of research has focused on the costs and benefits of dual or multiple sourcing in an inventory framework. The consensus has been that dual sourcing provides, in most cases, lower inventory-system costs under uncertain lead-time and demand conditions. Ramasesh et al. (1991) considered a continuous review inventory model with the order-fill policy in a dual sourcing setting. They used both uniform or exponential lead-times, and analyzed the associated costs and benefits, assuming that the lead-times were identical. Ramasesh et al. (1993) later extended their study on exponential lead-times by relaxing the assumption that lead-time distributions and the proportion of the order are the same for each supplier. Hong and Hayya (1992) investigated dual-sourcing in a Just-In-Time perspective and concluded that it may be used effectively to hedge uncertainty in a stochastic environment. More recently, Lao and Zhao (1993), and Chiang and Benton (1994) extended these dual sourcing studies to incorporate random demand, an unequal split between the suppliers, and any stochastic lead-time distribution.

3. The primary supplier scenario

In this section, we assume that the firm in question uses only its primary reliable supplier. To analyze the costs and benefits of using this single supplier, we develop a reorder point, order quantity model with the following assumptions:

- a (s, Q) continuous review inventory system, a single independent demand inventory item;
- an order fill service target (p_2) with complete back-ordering;
- period demand is normally distributed;
- the lead of the primary supplier is a discrete random variable (that includes the discrete approximation of a continuous random variable).

3.1. The cost analysis

Given a lot-size of Q and a reorder point of s , we consider the cost function of the form

$$\text{ETAC}(Q, s) = (R/Q)A + (Q/2)v_1i + \mu_D\mu_{T_1}v_1i + (s - \mu_L)v_1i + \text{TC}(Q) + Rv_1, \quad (1)$$

where $\text{ETAC}(Q, s)$ is the expected total annual costs, R the expected annual demand, A the cost of placing an order, v_1 the unit value ($\$$), i the holding cost factor ($\%$), D the period demand, assumed

to be a normally distributed random variable with mean μ_D (note that $R = 360\mu_D$) and standard deviation σ_D , T_1 the lead-time distribution, a random variable with mean μ_{T_1} and standard deviation σ_{T_1} , L a random variable representing the lead-time demand, with mean μ_L and standard deviation σ_L , and $TC(Q)$ the transportation costs as a function of the lot size, Q .

The first term in the cost function (1) represents the ordering costs. There are R/Q orders every year, each costing A dollars. The second term represents the cycle-stock holding costs. The average inventory in a cycle is $Q/2$ units. This is multiplied by the value of the product v_1 , times the holding factor, i (as a percentage of v_1 , to reflect opportunity cost tied up in inventory). The third term in the function is the in-transit or the pipeline stock holding cost. Each unit shipped will be in transit for an average of μ_{T_1} periods. Since the average demand per period is μ_D , an average of $\mu_D\mu_{T_1}$ units will be in transit. This is multiplied by the holding cost/year, v_1i (for convenience we assume that the holding factor for in-transit inventories is the same as i). The fourth term is the safety stock carrying costs. The safety stock is defined as the difference between the reorder point and the mean lead-time demand, i.e., $(s - \mu_L)$. The re-order level s is set so that a pre-determined level p_2 of orders are filled. The fifth term is the transportation cost. We assume that the transportation rates (per cwt) are a decreasing function of the amount shipped. In our model, we use the logarithmic function to estimate the transportation rates as a function of the lot-size, $a + b \ln(Q)$, $b < 0$ (see Arcelus and Rowcroft, 1991). The sixth term is annual item costs. Since R units are sold in a year, the annual purchasing costs are Rv_1 .

3.2. Solution procedures

Our method is similar in spirit to the one suggested by Banks and Fabrycky (1987), pp. 30–40, Eppen and Martin (1980), and later by Tyworth et al. (1996). The key observation is that when unit demand follows a normal distribution with mean μ_D and standard deviation σ_D , the conditional distribution of the demand given the lead time $t = j$, $j = 1 \dots n$ is also normal with mean $j\mu_D$ and standard deviation $\sqrt{j}\sigma_D$. One can therefore use well-known methods to calculate the expected shortages given $t = j$, $ESPRC_j$ as (Silver and Peterson, 1985, pp. 271–313)

$$ESPRC_j = G_u(k_j)\sigma_j, \quad (2)$$

where,

$$G_u(k_j) = \frac{1}{2\pi} \int_{k_j}^{\infty} (u - k_j) \exp\left(\frac{-u^2}{2}\right) \partial u, \quad (3)$$

$$k_j = (s - \mu_j)/\sigma_j,$$

$$\mu_j = j\mu_D, \quad \sigma_j = \sqrt{j}\sigma_D.$$

$G_u(k_j)$ can be calculated as $p(k_j) - k_j(1 - F(k_j))$, where $p(k_j)$ and $F(k_j)$ are the probability density function and the cumulative density function of the normal distribution respectively. The total expected shortages per replenishment cycle, $ESPRC$, is therefore

$$ESPRC = \sum_{j=1}^n ESPRC_j P_j, \quad (4)$$

where P_j is the probability that the lead-time, $T_1 = j$.

The traditional practice to find the levels of s and Q that satisfy the order-fill rate, p_2 , is to set

$$\text{ESPRC} = (1 - p_2)Q. \quad (5)$$

There are of course several pairs of (s, Q) that satisfy the above equation. The choice will depend on the overall objective of cost minimization.

Since our solution procedure warrants the use of a discrete lead-time distribution, we suggest a simple way to convert any continuous lead-time distribution to a discrete one. If $F_1(t)$ represents the cumulative density function (cdf) of the lead-time distribution, then the probability that $T_1 = j$ can be calculated as

$$P_j = P(T_1 = j) = F_1(F_1(j-1)), \quad j = 1 \dots n. \quad (6)$$

The practical way to implement the solution procedure is to use commercially available non-linear solvers (such as GINO or Microsoft Excel's SOLVER) to minimize Eq. (1) subject to the constraint posed in Eq. (5).

4. The two supplier scenario

In this section, we consider the case where the firm has a choice of a second 'unreliable' supplier. We define unreliable as having large lead-time means and variances. It is implicitly assumed that placing the order to *just* the second supplier is far more expensive than using just the primary one due to the increased safety, pipeline, and possibly cycle inventory and transportation costs. The second supplier, however, is willing to offset part of these increased costs by providing a price discount. The firm therefore has two key decisions to make – (i) whether to give a portion of its order to the second supplier (ii) if it does, what is the level of discount should be negotiated, and the percentage of the order should be placed for a given level of discount.

4.1. Model development

Fig. 1 illustrates the dynamics of dual sourcing assuming that Q' is the total order placed by the firm and f is the fraction that is ordered to the unreliable supplier. Therefore, when the reorder point is reached the firm places the order of size $Q'(1-f)$ to the primary supplier and $Q'f$ to the secondary supplier simultaneously. The first part of the order, $Q'(1-f)$, arrives at time $T_{[1]}$ (since the secondary supplier has long lead-times, we have assumed that the chances that this supplier will deliver before the first is negligible) and the shipment from the secondary supplier arrives at time $T_{[2]}$. Additionally, we have assumed, like most other authors, that the first shipment is the determinant of the overall service level. If T_2 is the lead-time distribution of the secondary supplier, then the time of arrival of the first shipment, $T_{[1]} = \min(E(T_1), E(T_2))$. Since $E(T_{[1]})$ is less than either $E(T_1)$ or $E(T_2)$ (Chow and Teicher, 1974, p. 85) the first shipment is now received *earlier* on an average. A second observation when using dual suppliers is the reduction of cycle inventories. For a given order size, the shaded area in Fig. 1 shows, on an average, the savings in

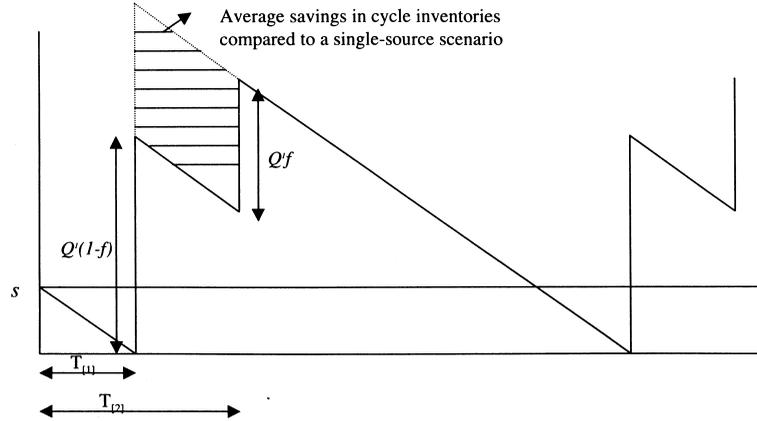


Fig. 1. Average inventory dynamics when two sources are in use.

cycle inventories when the two suppliers are in use. One can calculate the average in-cycle inventories, I_C , by subtracting the shaded area from the traditional formula ($Q'/2$):

$$I_C = Q'/2 - (\mu_{T_{[2]}} - \mu_{T_{[1]}})\mu_D f, \quad (7)$$

where $\mu_{T_{[2]}}$ and $\mu_{T_{[1]}}$ are the means of the second and the first arrival times respectively.

The total cost function can therefore be written as

$$\begin{aligned} \text{ETAC}'(Q', s') &= (R/Q')A' + I_C v_w i + [(1-f)\mu_D \mu_{T_1} v_1 i + f\mu_D \mu_{T_2} v_2 i] \\ &+ (s' - \mu_{L'})v_w i + \text{TC}(Q', f) + Rv_w, \end{aligned} \quad (8)$$

where ETAC' is the expected total annual cost when both suppliers are used, A' the combined ordering or setup cost for both suppliers, v_2 the item cost of the secondary supplier. If d is the percent discount offered by the secondary supplier, $v_2 = v_1(1 - d/100)$, f the fraction of the order placed to the secondary supplier, v_w the weighted price defined as $(1-f)v_1 + fv_2$, L' the lead time demand when both suppliers are used, a random variable with mean $\mu_{L'}$ and standard deviation $\sigma_{L'}$, μ_{T_2} the mean lead-time of the second supplier, s' the reorder level when both the suppliers are used. s' is calculated so that a pre-determined level of orders, p_2 , are filled, $\text{TC}(Q', f)$ the transportation costs when both the suppliers are used.

The first term in the cost function is the ordering cost per year. Since I_C is the amount of cycle inventory present when two suppliers are present, the second term is the cycle inventory carrying cost. The third term is the pipeline inventory carrying cost. An average of $(1-f)\mu_D \mu_{T_1}$ are in-transit from the primary supplier and therefore the pipeline carrying cost for just this supplier is $(1-f)\mu_D \mu_{T_1} v_1 i$. In a similar fashion, the pipeline carrying costs of the secondary supplier is $f\mu_D \mu_{T_2} v_2 i$. The fourth term is the safety stock carrying costs. As before, the safety stock in this case is defined as the difference between the reorder point and the mean lead-time demand. Recall that in the two-supplier scenario, the mean lead-time demand corresponds to the mean demand during the period the first shipment is in transit, i.e., demand during the random time $T_{[1]}$. The fifth term is the transportation costs. Since $(1-f)Q'$ and fQ' units are ordered from the primary and the secondary supplier every cycle, the total transportation rates for each of these shipments

are $a + b \ln((1 - f)Q')$ and $a + b \ln(fQ')$ respectively. Therefore the total transportation costs for the entire year is simply the sum of the costs from each supplier

$$TC(Q', f) = [a + b \ln(fQ')]fR + [a + b \ln((1 - f)Q)](1 - f)R. \quad (9)$$

The sixth term is the total purchase cost. Since $(1 - f)R$ and fR are the total amounts purchased from the primary and secondary supplier respectively, the total purchase price is $(1 - f)Rv_1 + fRv_2$ or Rv_w .

4.2. Solution procedure and heuristic

The solution procedure, for the most part, is identical to the single supplier scenario. The key observation here is that the service levels are based primarily on the first shipment. Since $(1 - f)Q'$ is received in time $T_{[1]}$, Eq. (5) is modified to

$$ESPRC' = (1 - p_2)Q(1 - f),$$

where $ESPRC'$ is the expected shortages per replenishment cycle when two suppliers are in use. As before,

$$ESPRC' = \sum_{j=1}^n ESPRC_j P_j^{[1]}. \quad (10)$$

$ESPRC_j$ is calculated exactly as before. The only difference in the computation is that $P_j^{[1]}$ now represents the probability that $T_{[1]} = j$. Let $F_{[1]}(t)$ denote the cumulative distribution function of $T_{[1]}$. Recognizing that $T_{[1]} = \min(T_1, T_2)$,

$$\begin{aligned} F_{[1]}(t) &= P(T_{[1]} \leq t) = 1 - P(T_{[1]} > t) \\ &= 1 - P(T_1 > t, T_2 > t) \\ &= 1 - (1 - F_1(t))(1 - F_2(t)). \end{aligned}$$

Therefore $P_j^{[1]}$ can easily be computed using the following formula:

$$P_j^{[1]} = F_{[1]}(j) - F_{[1]}(j - 1), \quad j = 1 \dots n. \quad (11)$$

The calculation of the cycle stock warrants the use of the mean of the arrival times of the first and the second shipment. We present one way to accomplish this. Let $P_j^{[2]}$ represent the probability that $T_{[2]} = j$. Let $F_{[2]}(t)$ denote the cumulative distribution function of $T_{[2]}$. Noting that $T_{[2]} = \max(T_1, T_2)$,

$$\begin{aligned} F_{[2]}(t) &= P(T_{[2]} \leq t) \\ &= P(T_1 \leq t)P(T_2 \leq t) \\ &= F_1(t)F_2(t). \end{aligned}$$

The probability $P_j^{[2]}$ can therefore be computed by using:

$$P_j^{[2]} = F_{[2]}(j) - F_{[2]}(j - 1), \quad j = 1 \dots n. \quad (12)$$

The means of the first and the second shipments can therefore be calculated as

$$\begin{aligned}\mu_{T_{[1]}} &= \sum_{j=1}^n jP_j^{[1]} \\ \mu_{T_{[2]}} &= \sum_{j=1}^n jP_j^{[2]}.\end{aligned}\tag{13}$$

The cycle inventories, I_C , can therefore be calculated easily.

We suggest a simple heuristic (illustrated through an example in the next section) that can be used to determine the discount that needs to be offered, and the portion of the order that should ideally be placed with the secondary supplier.

Step 1: Optimize Eq. (1) to determine the optimal value of ETAC for the single preferred supplier. This is the optimal cost of using just the primary supplier. For any order-splitting policy to be worth-while, the total cost of the two supplier scenario should be less than this cost. One can also optimize Eq. (1) with the corresponding parameters of *just* the second supplier. One would expect this cost to be much higher than ETAC of the primary supplier due to the excessive amounts of cycle, safety, and pipeline inventories that need to be used to buffer against the uncertainty of the secondary supplier. Additionally, one would also expect the cost of any split order to be in between these two costs.

Step 2: Optimize Eq. (8) with progressively increasing values of f (for example, one can start with 0.1, i.e., 10% of the order is given to the secondary supplier) to obtain $ETAC'$. For each f , compute the threshold level of discount the secondary supplier will need to offer so the total cost of using both the suppliers matches that of using just the first (i.e., the level of discount needed to make $ETAC' = ETAC$). As the fraction f increased, more units are purchased at a discounted price, and therefore the threshold level of discount needed also decreases. Depending upon the discount that is negotiated with the secondary supplier, the logistics manager can find the corresponding fraction (or can find the corresponding discount for a given fraction) that will make the total costs lower than ETAC.

5. A numerical illustration

This section considers an example of an hypothetical firm based in Cincinnati, OH. It purchases a product weighing one pound and costing 5/lb (v_1 is therefore 5) from two suppliers based around Chicago, IL. Daily demand for the product is normally distributed with mean (μ_D) 15 units and standard deviation (σ_D) of 7.5 units. Table 1 gives the other parameters used to illustrate our approach. We have used the gamma distribution to model the lead-time, T_1 , of the primary supplier. $f_1(t)$, the probability density function (pdf) of T_1 , is given by:

$$\begin{aligned}f_1(t) &= \frac{\alpha e^{-\alpha t} (\alpha t)^{\beta-1}}{(\beta)} & t \geq 0, \\ &0 & t < 0,\end{aligned}\tag{14}$$

where α and β are positive parameters.

Table 1
Parameters used in Section 5

Demand		
Mean daily demand	μ_D	15 units
Std. daily demand	σ_D	7.5 units
Days/year		360 days
Annual demand	R	5400 units
Inventory		
Unit Cost	v	5.00
Holding cost (%)	i	30%
Order fill rate	p_2	99.90%
Procurement		
Single supplier	A	150.00
Dual suppliers	A^1	200.00
Transportation		
Rate estimation	a	64.8264
	b	-5.6113
Lead-time		
Primary supplier	T_1	Gamma distributed with $\alpha=8.33$ and $\beta=0.6$
	μ_{T_1}	5 days
	σ_{T_1}	3 days
Secondary supplier	T_2	Exponentially distributed with $\lambda=0.04$
	μ_{T_2}	25 days
	σ_{T_2}	25 days

The mean (μ_{T_1}) and standard deviation (σ_{T_1}) can easily be calculated as:

$$\mu_{T_1} = \frac{\beta}{\alpha}, \quad \sigma_{T_1} = \sqrt{\frac{\beta}{\alpha^2}}. \tag{15}$$

In this illustration, we have used $\alpha = 8.33$ and $\beta = 0.6$ which gives us a mean and standard deviation of 5 and 3 days respectively. To account for the long lead-times, we have used the exponential distribution to model the lead-time of the secondary supplier. $f_2(t)$, the pdf of the exponential distribution is given by:

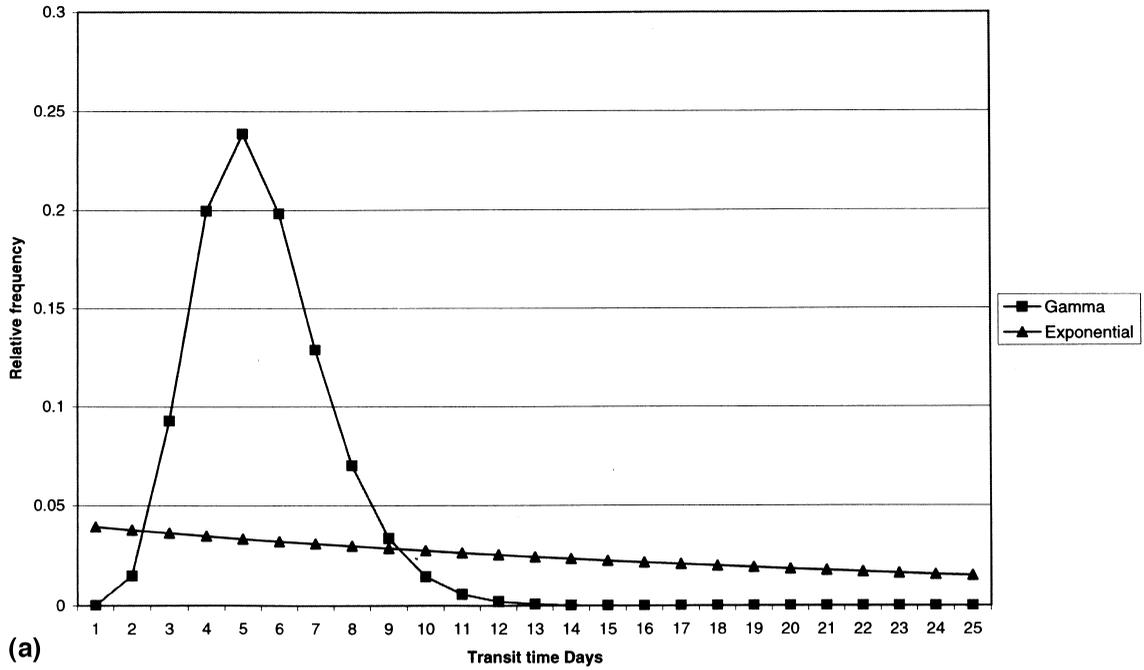
$$f_2(t) = \lambda e^{-\lambda t}, \quad t > 0,$$

where λ is a distributional parameter.

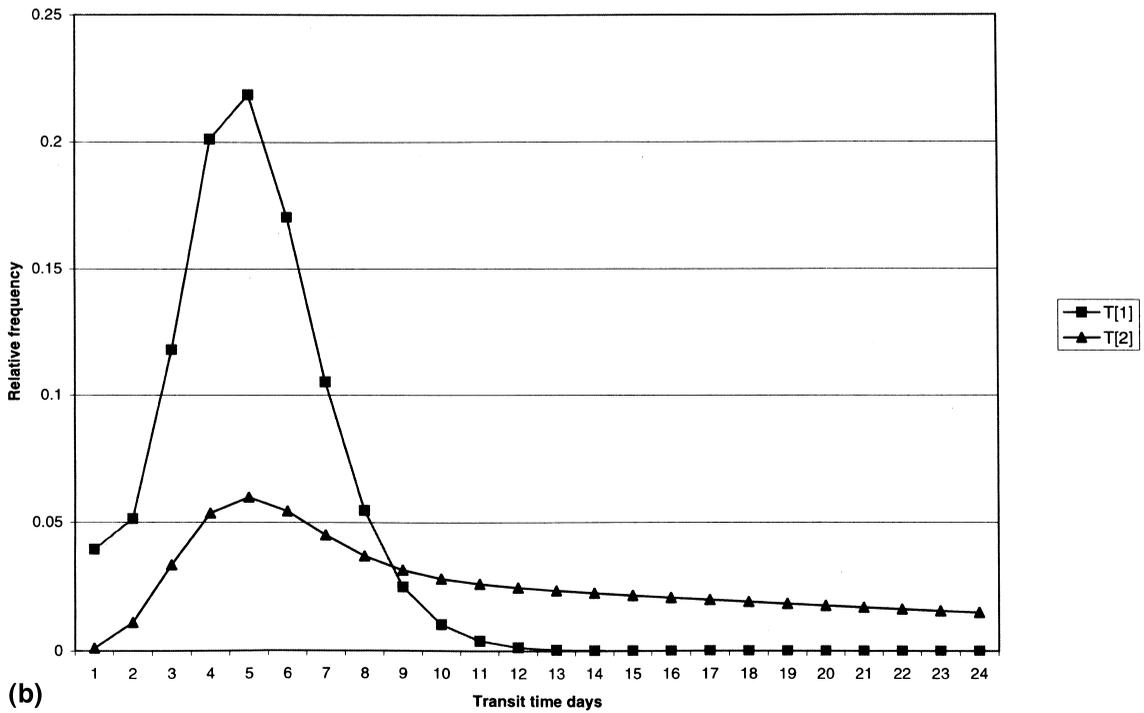
The mean (μ_{T_2}) and the standard deviation (σ_{T_2}) of this distribution are easily calculated as:

$$\mu_{T_2} = \frac{1}{\lambda}, \quad \sigma_{T_2} = \frac{1}{\lambda}. \tag{16}$$

In our case, we have used $\lambda = 0.04$ which gives us a mean and standard deviation of 25 days. Fig. 2(a) illustrates the lead-time distributions of the two suppliers. We use the procedure illustrated in Section 3.2 to optimize Eq. (1) subject to the constraint in Eq. (5). The optimization



(a)



(b)

Fig. 2. (a) The lead-times of the primary and the secondary suppliers. (b) The first and the second arrival distributions.

yields an ETAC value of 29,453 with the lot-size, Q , 1166, and the reorder point, s , 135.72. Using the same procedure, but substituting the relevant parameters of the secondary supplier, we can determine the cost of using just the secondary supplier. In our case ETAC' with $f=1$ (with no discount) is 30,794 with the lot-size and reorder point being 1226 and 1047 respectively. Obviously, the reorder point, and thus the safety inventories are higher (since shipment times are longer, the pipeline inventories are higher too!) due to the increased uncertainty associated with this supplier. The second step of our heuristic can be accomplished using the solution procedure outlined in Section 4.2. The first ($T_{[1]}$) and the second shipment ($T_{[2]}$) distributions can be calculated using Eqs. (13) and (14). Fig. 2(b) illustrates these two distributions. It can be noted that the first shipment arrives earlier on an average. We can optimize Eq. (8) for different values of f . Fig. 3 illustrates such a sensitivity analysis (they are also exchange curves). The figure plots the total optimal cost (each point in the graph is an optimal solution to Eq. (8)) for a given value of the fraction, f , and discount, d . From the figure, if just the secondary supplier is used, he needs to provide around 5% level of discount for ETAC' (with $f=1$)=ETAC. If the secondary supplier provides a discount $\geq 5\%$ it may be economical to use just this supplier. Although such a solution is impractical, the firm can use this data to leverage the prices of its primary supplier. If the firm is willing to order 30% of its requirements from the secondary supplier ETAC' (with $f=0.3$), any amount of discount level over 4.2% will make order splitting an economically attractive policy. This threshold level of discount, as the figure illustrates, will decrease with increasing f . If the secondary supplier is not willing to provide a discount of more than $\approx 2\%$ order splitting is

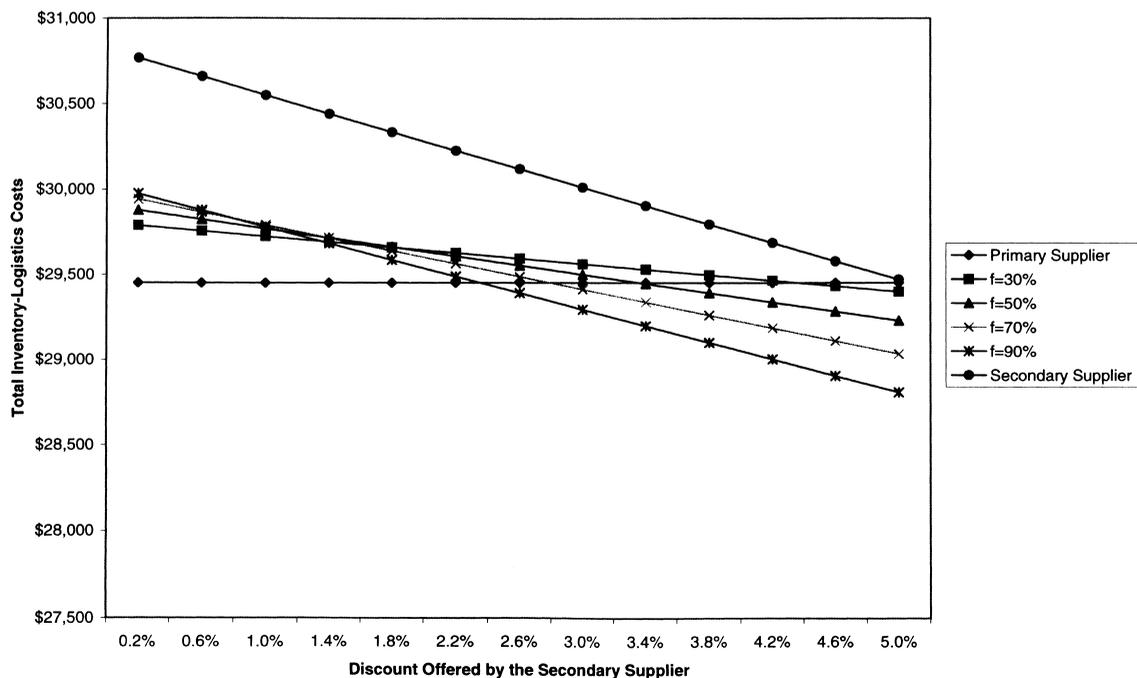


Fig. 3. Cost economics of dual-sourced supply chains.

clearly not favorable. A logistics manager can therefore use such exchange curves to negotiate an appropriate level of discount.

6. Summary and conclusions

We have examined the supply dynamics of a supply chain that has the option of using two suppliers – one reliable, and the other unreliable. We characterized the unreliable supplier with long lead-time means and variances. The unreliable supplier is attractive because he is willing to provide a discount on the purchase price. We analyzed the cost economics of two suppliers in a broader inventory-logistics framework that included in-transit inventories and transportation costs. In this broader perspective, we conclude that it may not always be favorable to split the order between the suppliers. The second supplier often needs to provide a price discount to make order-splitting a worth-while policy. We provide a simple heuristic and sample exchange curves to determine: (i) the amount of discount the secondary supplier needs to provide to make order-splitting a worth-while policy; and (ii) the fraction of the order that needs to be placed with the second supplier.

Our methodology was based on the assumption of normal period demands, and any uncertain lead-time distribution. The analysis can also be easily expanded to include several well-known forms of demand (see for example, Tyworth et al., 1996). Additionally, with minor modifications, our model can also accommodate a shortage model (p_1 criterion).

With the advent of Just-In-Time (JIT), many firms are using a single source and emphasis is placed on ‘trust’ and long term relationships. While we do not fault such an argument, our analysis indicates that, in the presence of a second supplier who’s willing to provide a price discount, logistics managers can potentially save on annual inventory-logistics by placing a fraction of the order to this cheaper supplier.

References

- Arcelus, F.J., Rowcroft, J.E., 1991. Small order transportation costs in inventory control. *The Logistics and Transportation Review* 27, 3–13.
- Banks, J., Fabrycky, W.J., 1987. *Procurement and Inventory System Analysis*. Prentice Hall, Englewood Cliffs, NJ.
- Cavinato, J.L., 1994. Sourcing and supplier management. In: Robeson, J.F., Copacino, W.C., (Eds.), *The Logistics Handbook*. The Free Press, NY, pp. 411–426.
- Chiang, C., Benton, W.C., 1994. Sole sourcing versus dual sourcing. *Naval Research Logistics* 41, 609–624.
- Chow, Y.S., Teicher, H., 1974. *Probability Theory*. Springer, New York.
- Eppen, G.D., Martin, R.K., 1980. Determining safety stock in the presence of stochastic lead time and demand. *Management Science* 34, 1380–1390.
- Guo, Y., Ganeshan, R., 1995. Are more suppliers better?. *Journal of the Operational Research Society* 46(5), 892–896.
- Hayya, J.C., Christy, D.C., Pan, A.C., 1987. Reducing inventory uncertainty: a reorder point system with two vendors. *Production and Inventory Management* 2nd Qtr, 43–49.
- Hill, R.M., 1996. Order splitting in continuous review (Q, r) inventory models. *European Journal of Operational Research* 95, 53–61.
- Hong, J., Hayya, J.C., 1992. Just-In-Time purchasing: single or multiple sourcing?. *International Journal of Production Economics* 27, 175–181.

- Kelle, P., Silver, E.A., 1990. Safety stock reduction by order splitting. *Naval Research Logistics* 37, 725–743.
- Kelle, P., Silver, E.A., 1990. Decreasing expected shortages through order splitting. *Engineering Costs and Production Economies* 19, 351–357.
- Lao, H., Zhao, L.G., 1993. Optimal ordering policies with two suppliers when lead times and demands are all stochastic. *European Journal of the Operational Research Society* 68, 120–133.
- Newman, R.G., 1988. Single sourcing: short term saving versus long term problems. *Journal of Purchasing and Materials Management* 25(2), 20–25.
- Pan, A.C., Ramasesh, R.V., Hayya, J.C., Ord, J.K., 1991. Multiple sourcing: the determination of lead time. *Operations Research Letters* 14, 1–7.
- Ramesesh, R.V., Ord, J.K., Hayya, J.C., 1993. Note: dual sourcing with non-identical suppliers. *Naval Research Logistics* 40, 279–288.
- Ramasesh, R.V., Ord, J.K., Hayya, J.C., Pan, A.C., 1991. Sole versus dual sourcing in stochastic lead-time (sQ) inventory models. *Management Science* 37, 428–443.
- Sculli, D., Shum, Y.W., 1990. Analysis of continuous review stock-control model with multiple suppliers. *Journal of the Operational Research Society* 419, 873–877.
- Sculli, D., Wu, S.Y., 1981. Stock control with two suppliers and normal lead times. *Journal of the Operational Research Society* 32, 1003–1009.
- Sheridan, J.H., 1988. Strategic Manufacturing: betting on a single source. *Industry Week* 236(3), 31–36.
- Silver, E.A., Peterson, R., 1985. *Decision Systems for Inventory Management and Production Planning*. Wiley, New York.
- Tyworth, J.E., Guo, Y., Ganeshan, R., 1996. Inventory control under gamma demand and random lead time. *Journal of Business Logistics* 17(1), 291–304.