Int J Adv Manuf Technol (2005) 26: 1421–1428
DOI 10.1007/s00170-004-2118-3

ORIGINAL ARTICLE

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Economical delivery strategies of products in a JIT system under a global supply chain

Received: 31 December 2003 / Accepted: 30 January 2004 / Published online: 8 December 2004

Abstract This study supplies an optimal total cost model, including approach I and approach II, to manufacturers with several assemblers in the same area to decide the most economical product delivery strategy in the global just-in-time (JIT) system. In approach II, manufacturers deliver products to downstream assemblers via a JIT system with third party logistics (3PL) support. There is a distinction between approach I and approach II according to whether or not the delivery quantity is limited to economical delivery lot size. A case study analysis is used to illustrate the proposed models, in which the following conclusions can be obtained. Firstly, the JIT product delivery strategy according to economical delivery lot size can be obtained to achieve a cost-effective global supply chain. Second, upstream manufacturers can apply a JIT system under a global supply chain to downstream manufacturers with lower cost through support from 3PL with economical delivery lot size.

Keywords Cost model · Delivery lot size · Global supply chain · JIT · Production lot size · Third party logistics

1 Introduction

With globalization of businesses, delivering products quickly and on time has become more and more important and requires the support of a logistics system. Outsourcing logistics activities to specialized service providers often presents an economically viable method of achieving productivity and/or service enhancements [1].

Companies can take advantage of the just-in-time (JIT) approach to achieve goals such as cost reduction, lead-time reduction, quality assurance, and respect for humanity [2]. Since the performance of the supplier can be evaluated by various criteria including lead times, on-time delivery, delivery reliability, quality, and cost [3], deploying the JIT system is crucial in improving customer satisfaction. Goetschalckx et al. [4] stated that long-range survival for international corporations will be very difficult to attain without highly optimized strategic and tactical global logistics plans. Global corporations must constantly evaluate and configure their production systems, distribution systems, and strategies to provide desired customer service at the lowest cost.

According to the JIT policy, every manufacturer must deliver the right amount of components, at the right time, and to the right place [5]. Owing to the short product life cycle of the personal computer industry, upstream manufacturers are commonly required to offer products to downstream assemblers in the JIT system to reduce the risk of price loss incurred from inventory. A global supply chain has become popular because the upstream and the downstream processes divide the labor. Take Taiwanese personal computer (PC) peripheral products companies, for example. These companies have encountered such a price loss from inventory problems in JIT systems with a global supply chain. Accordingly, the purpose of this study is to provide manufacturers with two distinct delivery strategies in terms of whether their products have economical delivery lot size to make the right decision to lower cost. In addition, this study also proves the effect of delivery strategy on cost in the JIT system under a global supply chain as shown by the case of one multi-product Taiwanese electronics company with several assemblers in the same area.

2 Literature review

Zimmer [6] addressed the issue of when JIT purchasing is implemented, the production of products largely depends on the on-time delivery of components, which can drastically reduce buffer inventories. In addition, Zimmer [6] regarded the supply chain as a network of companies with conflicting profit motives.

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When manufacturers have to comply with assemblers in the JIT system, inventories of manufacturers will increase to offset the reduction of assemblers' inventories [6–8].

Economic order quantity (EOQ) is widely used in calculating optimal lot size to achieve cost benefit in the JIT system [7–10], where total cost in the JIT system can be divided into four cost groups, including ordering cost, setup cost, inventory holding cost for raw materials and manufactured products [7, 8]. David and Chaime [8] further discussed a vendor-buyer relationship to include two-sided transportation costs in the JIT system.

Hertz and Alfredsson [11] considered a third party logistics (3PL) provider as an external provider who manages, controls, and delivers logistics activities on behalf of a shipper. 3PL incorporates services such as inventory management, warehousing, procurement, transportation, systems administration, information systems, materials subassembly, contract manufacturing, kitting, and import and export assistance [12].

Koulamas [13] and Otake et al. [14] illustrated the annual setup cost as being equal to the individual setup cost times the total number of orders in a year. McCann [15] and Tyworth and Zeng [16] both considered transportation cost to include freight rate, annual demand, and weight. The above literature assumes constant charge per unit in contrast with Swenseth and Godfrey [17], who assumed constant charge per shipment leading to economies of scale. Besides, McCann [15] presented total logistics costs as the sum of ordering costs, holding costs, and transport costs. As for cost incurring from a distribution center, Syarif et al. [18] considered both transportation cost and fixed cost for operation from distribution center to customer. Taniguchi et al. [19] also took costs of pickup/delivery and land-haul trucks into consideration.

3 The formulation of the JIT optimal total cost model

Before developing the cost models, the symbols and notations used throughout this study are listed here:

B_a Annual inventory holding cost of 3PL (amount per year)
B_b 3PL's pickup cost per unit of product (amount per unit)
C_L Cost of 3PL (amount per year)
D Assemblers' total demand at a regular interval, where $D = \sum_{j=1}^{n} d_j$ (units per shipment)
D_p Annual demand rate of product (units per year)
D_r Annual demand of raw materials (units per year)
d_j The fixed quantity-periodic demand for the assembler j
F_{LAj} Freight rate from 3PL to assembler j, where $j = 1, 2, \ldots, n$ (amount per kilogram)
F_{MAj} Freight rate from manufacturers to assembler j, where $j = 1, 2, \ldots, n$ (amount per kilogram)
F_{ML} Transportation cost from manufacturers to 3PL (amount per lot)
H_p Inventory holding cost of product per unit (amount per year)
H_r Inventory holding cost of raw materials per unit (amount per year)
I_p Average inventory of products (units)
i Annual profit rate of 3PL (%)
k Maximum shipments from 3PL to assemblers required under each manufacturer's delivery lot size to 3PL ($= Q_t/D$, times per delivery lot size)
M^* Exact number of shipments reaching optimal cost
m Number of shipments
m^* Potential number of shipments reaching optimal cost
P Production rate of product (units per year)
Q_p Production lot size (units per lot)
Q_p^* Optimal production lot size (units per lot)
Q_r Ordering quantity of raw materials (units per order)
Q_T Real delivery lot size (units per lot)
Q_t Maximum delivery lot size (units per lot)
R_r Ordering cost (amount per order)
r Real shipments from 3PL to assemblers required under each manufacturer's delivery lot size to 3PL ($= Q_T/D$, times per delivery lot size)
S Delivery lot size (units per lot)
S_p Setup cost (amount per setup)
w Weight of product (kilogram per unit)
λ Quantity of raw materials required in producing one unit of a product (units)

For the sake of simplifying the model, this study makes general assumptions of the JIT system as follows:

1. The production rate of manufacturers is uniform, finite, and higher than the demand rate of assemblers
2. There is no shortage and the quality is consistent for both raw materials and products
3. The manufacturer has j assemblers and each assembler's demand is fixed during the same interval, where $j = 1, 2, 3, \ldots, n$,
4. Q_t is much larger than the total demand at a regular interval, D ($Q_t \gg D$),
5. 3PL can serve all assemblers in the same area
6. The delivery out of 3PL belongs to short distance, where the delivery cost will not be affected by lot size

A supply chain contains five levels, including raw materials supplier, manufacturer, assembler, warehouse, and consumer [20]. This study mainly focuses on the relationship between manufacturer and assembler in the JIT system under a global supply chain. In order to control inventories of assemblers and to achieve a fixed quantity-periodic policy, manufactures will have to undertake significantly higher transportation costs instead of regularly applying economical delivery lot size due to the requirement of the JIT system under a global supply chain.

In this study, the JIT system under a global supply chain has been constructed using two approaches depending on whether manufacturers can deliver in economical delivery lot size or not: (1) approach I: manufacturers deliver products in a fixed quantity-periodic policy according to the needs of assemblers (Fig. 1), and (2) approach II: manufacturers utilize overseas ser-

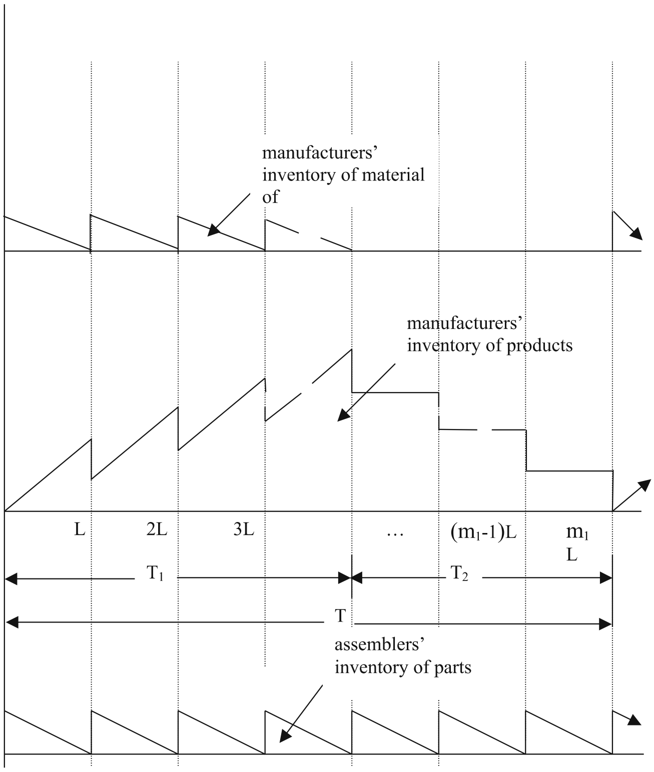

Fig. 1. Inventory level of approach I

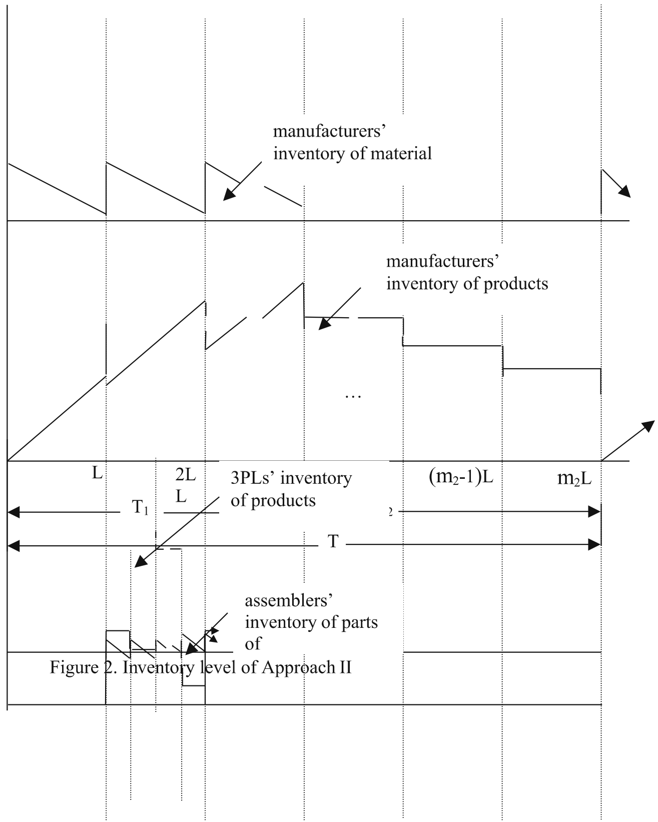

Fig. 2. Inventory level of approach II

vice from 3PL with economical delivery lot size and with 3PL then delivering using a fixed quantity-periodic policy to assemblers in the JIT system under a global supply chain (Fig. 2). While approach I fits assumptions (1), (2), and (3), approach II is in line with assumption (1) to (6).

According to assumption (3), assemblers have the same demand interval and each assembler's demand is fixed, so the total assembler's demand is fixed quantity-periodic. Therefore, the number of shipments (m) must be an integer in the JIT system.

Approach I is mainly developed for manufacturers whose products are not limited to economical delivery lot size. In Fig. 1, the upper level demonstrates the inventory of manufactures' raw materials. According to the policy of one-shot raw materials procurement in the JIT delivery system presented by Khan and Sarker [7], suppliers have to support raw materials according to the exact demand of manufacturers during the period T_1. The middle level represents the inventory of parts from the manufacturer. The bottom level illustrates the inventory parts from the assembler, which is identical to parts from manufacturers in this study. It is assumed that assemblers have a fixed demand d during fixed interval L. According to assumption (1), manufacturers' production rate P is larger than the assemblers' demand rate D_p with fixed quantity delivery during every interval L. During a production cycle T, manufacturers only produce during period T_1 to establish their inventory. During period T_2, manufacturers stop production with continuous delivery, which gradually consumes built-up inventory. Manufacturers' inventory of products would demonstrate the sleek pattern only if assumption (2) exists.

Approach II proposes an alternative to seeking 3PL support in the JIT system under a global supply chain. This approach is illustrated in Fig. 2. The upper level is the manufacturers' inventory of raw materials. Similarly to approach I, the second level is the parts inventory of the manufacturer, which gradually builds up because the production quantity is larger than the demand quantity during period T_1. However, during period T_2, the inventory of parts will decrease due to production stops. The actual delivery lot size of products per time is Q_T and most products' stock in the position of manufacturers. The third level is the inventory of 3PL. The bottom level is the inventory of assemblers. In Fig. 2, there is more inventory of products left with manufacturers than in 3PL, which can be explained by a two-sided inventory pattern from David and Chaime [8]. According to this inventory pattern, the total of vendors' and buyer's average inventory is fixed when the constant demand rate, D_p, is larger than the constant production rate, P, in the JIT system. Because the manufacturers' inventory holding costs of products are lower in manufacturers, there exists an inventory pattern shown in Fig. 2. In the same manner as approach I, approach II should accord with assumptions (1) and (2). The next step is to construct a manufacturer's optimal total cost model under the global JIT, including cost of manufacturing and cost of logistics.

3.1 The construction of total cost of manufacturing (TCM)

The annual total cost of manufacturing (TCM) in the JIT system can be determined as follows:

$$\mathrm{TCM} = \frac{D_r}{Q_r} R_r + \frac{D_p}{P}\left(\frac{S}{2}\lambda\right) H_r + \frac{D_p}{Q_p} S_p + I_p H_p \tag{1}$$

and the average inventory of products (I_p) is:

$$I_p = \left(1 - \frac{D_p}{2P}\right) Q_p - \left(\frac{m-1}{2}\right) S\,. \tag{2}$$

In Eq. 1, the first term is the ordering cost of raw materials. The second term is inventory holding cost of raw materials. The third term is the set up cost of production. The final term is inventory holding cost of products. Equations 1 and 2 are derived from the model presented by Sarker and Parija [6], Khan and Sarker [7], and Aderohunmu et al. [21]. In Eq. 2, manufacturers' delivery lot size using approach I is different from using approach II, as manufacturers deliver products using approach I,

$$S = D = \sum_{j=1}^{n} d_j\,. \tag{3}$$

According to assumption (5), because assemblers are in the same area, the third party logistics can serve the assemblers together and the d_j could be added. In Eq. 3, because each d_j is fixed at the same regular demand interval, the sum of d_j is D. It can be obtained as follows after substituting Eq. 3 into Eq. 2:

$$I_p = \left(1 - \frac{D_p}{2P}\right) Q_p - \left(\frac{m-1}{2}\right) D\,. \tag{4}$$

On the other hand, when manufacturers deliver products using approach II, it is essential to figure per delivery lot size, S. It is essential to substitute Q_T for Q_t, for lower inventory in 3PL and fulfill the fixed quantity-periodic demand of the assembler. Manufacturers' maximal delivery lot size, Q_t, is a k multiple of total demand, D, of the assembler. Therefore,

$$k = \frac{Q_t}{D}\,. \tag{5}$$

In order not to meet the delivery requirement, r must be an integer and as follows:

$$r = \begin{cases} k & \text{when } k \text{ is an integer} \\ \lfloor k \rfloor & \text{otherwise.} \end{cases} \tag{6}$$

The real delivery lot size, Q_T, is as follows:

$$S = Q_T = rD\,. \tag{7}$$

The following results are obtained after substituting Eq. 7 into Eq. 2:

$$\begin{aligned} I_p &= \left(1 - \frac{D_p}{2P}\right) Q_p - \left(\frac{m-1}{2}\right) Q_T \\ &= \left(1 - \frac{D_P}{2P}\right) Q_P - \left(\frac{m-1}{2}\right) rD\,. \end{aligned} \tag{8}$$

The optimal production lot size, Q_p^*, for manufacturers can therefore be determined through calculation of the optimal number of shipments, m^*, during production cycle T. Because the manufacturers' production lot size is identical to the total demand of the assembler during the production cycle, accordingly,

$$Q_P = mS\,. \tag{9}$$

The multiple λ is the quantity of raw materials required in producing one unit product. Therefore, the relationship between the demand for raw materials and products can be illustrated as follows:

$$\frac{D_r}{D_p} = \lambda = \frac{Q_r}{Q_p}\,. \tag{10}$$

Accordingly, the demand of raw materials, Q_r, based on production lot size can be illustrated as follows:

$$Q_r = \lambda Q_p\,. \tag{11}$$

By substituting Eq. 9 into Eq. 11, Q_r can be further developed as:

$$Q_r = \lambda m S\,. \tag{12}$$

In order to provide manufacturers with the optimal production model as a reference for decision making, Eq. 1 can be developed, which is a convex function [7]:

$$\begin{aligned} \mathrm{TCM}(m) = {} & \frac{(P - D_p)\, S H_p}{2P} m + \frac{D_p (R_r + S_p)}{S} m^{-1} \\ & + \frac{D_p}{P}\left(\frac{S}{2}\lambda\right) H_r + \frac{S}{2} H_p\,. \end{aligned} \tag{13}$$

The optimal number of shipments, m^*, can be obtained by differentiating TCM with respect to m,

$$m^* = \frac{1}{S}\left(\frac{2PD_p (R_r + S_p)}{(P - D_p) H_p}\right)^{\frac{1}{2}}\,. \tag{14}$$

In Eq. 13, annual delivery cost is based on annual demand of products (D_p), not the function of m^*, since optimal number of shipments in this model, M^*, is an integer and should reach the minimum total cost of manufacturing. Therefore,

$$M^* = \left\{ m \,\middle|\, \mathrm{TCM}(m) = \mathrm{TCM}^*,\ \lfloor m^* \rfloor \le m \le \lceil m^* \rceil,\ m \in \mathrm{Z} \right\}. \tag{15}$$

Substituting M^* for m in Eq. 13 will get the optimal cost of this model as follows:

$$\mathrm{TCM}^* = \mathrm{TCM}\left(M^*\right). \tag{16}$$

Optimal production lot size in this model, Q_p^*, is the exact number of shipments, M^*, multiplied by the total assemblers' demand at a regular interval, S:

$$Q_P^* = M^* S\,. \tag{17}$$

The optimal production lot size in Eq. 17 will produce an optimal TCM. When manufacturers deliver products using approach I, the following will be obtained after substituting Eq. 3 into Eq. 14 and Eq. 17 separately:

$$m^* = \frac{1}{D}\left(\frac{2PD_p\left(R_r+S_p\right)}{\left(P-D_p\right)H_p}\right)^{\frac{1}{2}} \tag{18}$$

and

$$Q_P^* = M^* D\,. \tag{19}$$

On the other hand, when manufacturers deliver products using approach II, the following result will obtained after substituting Eq. 7 into Eq. 14 and Eq. 17.

$$m^* = \frac{1}{rD}\left(\frac{2PD_p\left(R_r+S_p\right)}{\left(P-D_p\right)H_p}\right)^{\frac{1}{2}} \tag{20}$$

and

$$Q_P^* = M^* Q_T = M^* rD \tag{21}$$

The next step is to discuss the cost of logistics.

3.2 The construction of the total cost of logistics (TCL)

The annual total cost of logistics in approach I (TCL_1) in the JIT system can be determined as follows:

$$\mathrm{TCL}_1 = \frac{D_p}{D}\sum_{j=1}^{n} d_j w F_{MAj}\,. \tag{22}$$

In Eq. 22, the delivery cost of products is in proportion to the weight and freight rate [12, 13]. The annual total cost of logistics in approach II (TCL_2) is determined as follows:

$$\mathrm{TCL}_2 = \frac{D_P}{Q_T}F_{ML} + (1+i)\,C_L \tag{23}$$

and the cost of 3PL (C_L) is illustrated as follows:

$$C_L = \frac{Q_T}{2}B_a + D_p B_b + \frac{D_p}{D}\sum_{j=1}^{n} d_j w F_{LAj}\,. \tag{24}$$

In Eq. 23, the first term is cost from production to 3PL. The second term is the logistics cost of the manufacturer, which must afford both 3PL (C_L) and their profit (the profit ratio is i). The 3PL's cost in equation Eq. 24 includes inventory holding cost, pickup cost, and delivery cost of products, which was proposed by Taniguchi et al. [19]. According to assumption (6), the delivery cost is calculated with view to the weight of product, not limited to delivery lotexists size.

3.3 The optimal total cost model

When the manufacturer uses approach I, the optimal total cost (OTC) of approach I (TC_1^*) can be obtained by adding together the TCM (M^*) (Eq. 13) and the TCL_1 (Eq. 22). On the other hand, adding together the TCM (M^*) (Eq. 13) and the TCL_2 (Eqs. 23 and 24), gives the OTC of approach II (TC_2^*). The OTC can, therefore, be formulated as follows:

$$OTC = \text{Minimize}\ \left\{TC_1^*, TC_2^*\right\} \tag{25a}$$

$$\begin{aligned} TC_1^* &= \mathrm{TCM}\left(M^*\right) + \mathrm{TCL}_1 \\ &= \frac{\left(P-D_p\right)DH_p}{2P}M^* + \frac{D_p\left(R_r+S_p\right)}{D}M^{*-1} \\ &\quad + \frac{D_p}{P}\left(\frac{D}{2}\lambda\right)H_r + \frac{D}{2}H_p + \frac{D_p}{D}\sum_{j=1}^{n} d_j w F_{MAj} \end{aligned} \tag{25b}$$

$$\begin{aligned} TC_2^* &= \mathrm{TCM}\left(M^*\right) + \mathrm{TCL}_2 \\ &= \frac{\left(P-D_p\right)Q_T H_p}{2P}M^* + \frac{D_p\left(R_r+S_p\right)}{Q_T}M^{*-1} \\ &\quad + \frac{D_p}{P}\left(\frac{Q_T}{2}\lambda\right)H_r + \frac{Q_T}{2}H_p + \frac{D_P}{Q_T}F_{ML} \\ &\quad + (1+i)\left(\frac{Q_T}{2}B_a + D_p B_b + \frac{D_p}{D}\sum_{j=1}^{n} d_j w F_{LAj}\right). \end{aligned} \tag{25c}$$

In Eq. 25a, the manufacturer chooses the way of lower production and delivery cost between optimal total cost (TC_1^*) of approach I and optimal total cost (TC_1^*) of approach II. OTC is the lower one between TC_1^* and TC_2^*. In Eq. 25c, when k in Eq. 6 is not an integer, Q_T will be smaller than Q_t, and $\frac{Q_T}{Q_t}$ is smaller than 1. Therefore, it is possible that the number of shipments of products will increase with each optimal production lot size. Consequently, there must exist a constraint equation in approach II (Eq. 25c) as follows:

$$1 - \frac{1}{M^*} < \frac{Q_T}{Q_t} \leq 1(\text{Appendix A})\,. \tag{26}$$

When Eq. 26 holds, manufacturers will not be able to increase the number of shipments. Furthermore, the inventory of 3PL will not increase even though manufacturers deliver products in Q_T, which is smaller than Q_t. In Eq. 26, when the assumption $Q_t \gg D$ holds, the loading ratio of maximum delivery lot size of products, $\frac{Q_T}{Q_t}$, approaches 1 because k is relatively larger. Accordingly,

$$\frac{Q_T}{Q_t} \approx 1,\ \text{when}\ Q_t \gg D\,. \tag{27}$$

When Eq. 27 holds, $\frac{Q_T}{Q_t}$ will approach 1, and manufacturers will match Eq. 26 unless M^* is extremely large. Therefore, when manufacturers conform to the assumption $Q_t \gg D$ in approach II, they will match Eq. 26. In addition, assumption (4) in this model will make manufacturers match the constraint equation in this model as follows:

$$1 - \frac{1}{M^*} < \frac{Q_T}{Q_t} \leq 1,\ \text{when}\ Q_t \gg D\,. \tag{28}$$

The above is the exploration of approaches I and II. The next section will be cases studies in Taiwan concerning the producer' practice regarding two kinds of products in the JIT system under a global supply chain with regard to customers' requests and further experimental study of optimal total cost models.

3.4 The economical delivery strategy decision

The delivery strategy decision for each specific product will be different according to whether or not individual total cost will be significantly affected by economical delivery lot size. Therefore, it is essential to apply approaches I and II to obtain the total cost in order to decide economical delivery strategy. In view of putting approaches I and II on the same basis, this study assumes that assemblers are in the same area that can be served by one 3PL.

4 Case study

Taiwanese PC upstream manufacturers have already become major players in the global supply chain. Accordingly, the delivery strategies will significantly decide whether manufacturers can achieve the goal of supplying fixed periodic-quantity products with lower cost. The manufacturer in this case study is a transnational one producing PC peripheral products, including printers, scanners, rigid printed circuits boards (PCBs), and optical drives, etc. This study considers rigid PCBs and optical drives, being sold to China and Europe, as examples to ascertain economical delivery strategies through the approaches I and II.

4.1 Case 1: a rigid PCB product

The product in this case, rigid PCBs, is used in the manufacturing of PCs and other electronic products. Presently, several assemblers in Shang-hai, China, producing PCs require shipments by air every day. This means of delivery fits the JIT system under a global supply chain.

The relative information about the product is as follows: $d_1 = 400$, $d_2 = 350$, $d_3 = 250$, $\lambda = 1$, $D_P = 250\,000$, $P = 300\,000$, $H_r = 2.5$, $H_p = 4.0$, $R_r = 300$, $S_p = 2000$, $F_{MA1} = 11$, $F_{MA2} = 12$, $F_{MA3} = 15$, and $w = 0.25$. Substituting the above information into Eq. 3 will obtain $D = 1000$ and substituting this information into Eq. 18 will obtain $m^* = 41.53$. Since m must be an integer, the next step is to place $m = 41$ and $m = 42$ into Eq. 13, respectively, to decide the optimal cost according to Eq. 16. When $m = 41$, TCM(41) of approach I is \$30 733, and when $m = 42$, TCM(42) is \$30 399. Accordingly, the optimal cost of this case, TC_1^*, is \$802 274 in Eq. 25b, with the optimal numbers of shipments per lot size, M^*, as 42. By substituting $M^* = 42$ into Eq. 19, the optimal production lot size, Q_p^*, can be calculated as 42 000 units.

On the other hand, when manufacturers deliver products according to approach II, additional information is needed as follows: $Q_t = 10400$, $F_{ML} = 3000$, $i = 0.1$, $B_a = 4.0$, $B_b = 1.2$, and $F_{LA1} = 5.4$, $F_{LA2} = 4.2$, $F_{LA3} = 5.0$. The results are that $k = 10.4$ and $r = 10$, are obtained by substituting the information given above in Eqs. 5 and 6. While substituting $r = 10$ and $D = 1000$ into Eqs. 7 and 20, the actual delivery lot size, Q_T, 10 000 units and, m^*, 4.15 can be calculated, respectively. If $m = 4$, TCM(4) will be \$58 125, and if $m = 5$, TCM(5) becomes \$58 583. Therefore, the optimal cost of approach II, TC_2^*, is calculated as \$820 625 after substituting the above results in Eq. 27 and the optimal shipments per lot size, M^*, is 4. By substituting $M^* = 4$ into Eq. 21, the optimal production lot size, Q_p^*, becomes 40 000 units (Table 1). In addition, this case study places $M^* = 4$ and $\frac{Q_T}{Q_t} = 0.962$ into Eq. 26 to ascertain that the manufacturer will not increase delivery cost with $Q_T = 10\,000$ units.

Table 1. Economical delivery strategy for Case 1

Approach I ($m^* = 41.53$)	$M^* = 42$	$TC_1^* = \$802\,274$
Approach II ($m^* = 4.14$)	$M^* = 4$	$TC_2^* = \$820\,625$

OTC = \$802 274 Economical delivery strategy: approach I ($TC_1^* < TC_2^*$)

Accordingly, the optimal cost of approach I, TC_1^*, is \$802 274, which is much lower than the TC_2^* of \$820 625 from approach II. Therefore substituting the above results into Eq. 25a obtains a manufacturers' OTC of \$802 274. The rationale behind this case study is the volume of rigid PCB is small and light weight and it is not constrained by any economical lot size of airway delivery.

4.2 Case 2: an optical drive product

The product in this case is an optical drive. The downstream assemblers in France, Italy, and Germany require fixed quantity-periodic delivery under the JIT system. The manufacturer delivers products to distribution center in Holland to meet customer demand.

The product is delivered in containers and the maximum delivery lot size is $Q_t = 9600$. Other information regarding manufacturers includes: $d_1 = 450$, $d_2 = 320$, $d_3 = 770$, $D_p = 385\,000$, $P = 420\,000$, $\lambda = 1$, $H_r = 1.2$, $H_P = 1.8$, $R_r = 200$, $S_P = 3300$, $F_{ML} = 2500$, $i = 0.1$, $B_a = 1.8$, $B_b = 1.0$, $w = 0.8$, $F_{LA1} = 1.2$, $F_{LA2} = 1.8$, and $F_{LA3} = 2.2$. Therefore, substituting the information given above into Eqs. 3, 5, and 6 results in $D = 1540$, $k = 6.23$, and $r = 6$. After this, $r = 6$ and $D = 1540$ are substituted into Eq. 7 to reach real delivery lot size, Q_T, as 9240 units. Accordingly, $m^* = 14.51$ can be found from Eq. 20. Since m^* must be an integer, $m = 14$ and $m = 15$ in Eq. 13 have to be tested separately to decide the optimal cost according to Eq. 15. When $m = 14$, TCM(14) is \$123 572; and when $m = 15$, TCM (15) is \$117 319. Therefore, the optimal cost using approach II, TC_2^*, is \$684 117 and in Eq. 25c with the optimal numbers of shipments, M^* of 15. By substituting $M^* = 15$ into Eq. 21, the optimal production lot size, Q_p^*, of 138 600 is therefore reached. Finally, $M^* = 15$ and $\frac{Q_T}{Q_t} = 0.963$ are put into Eq. 26 and the results show that the manufacturer will not increase delivery cost with a $Q_T = 9240$ units.

Table 2. Economical delivery strategy for Case 2

Approach I ($m^* = 87.03$)	$M^* = 87$	$TC_1^* = \$880\,024$
Approach II ($m^* = 14.51$)	$M^* = 15$	$TC_2^* = \$684\,117$

OTC = \$684 117 Economical delivery strategy: approach II ($TC_1^* > TC_2^*$)

This manufacturer operated in accordance with approach I before the construction of a distribution warehouse in Holland. Some extra data needed to demonstrate approach II is as follows: $F_{MA1} = 2.6$, $F_{MA2} = 2.3$, and $F_{MA3} = 2.5$. The number of shipments, $m_1^* = 87.03$, can be obtained using to Eq. 18. Furthermore, $m = 87$ and $m = 88$ in Eq. 13 are tested separately to decide the optimal cost according to Eq. 16. When $m = 87$, TCM(87) is \$113 915, and when $m = 88$, TCM(88) is \$115 177. Therefore, the optimal cost of approach I, TC_1^*, is \$880 024, which is much higher when compared with the TC_2^*, \$684 117, of approach II (Table 2). Accordingly, the support of 3PL with economical delivery lot size demonstrates its superior cost advantage.

The product in this case study presents the characteristics of large volume and heavy weight, which is suitable for shipments by container with economical delivery lot size. Cases studies 1 and 2 demonstrate that different products requires distinct economical delivery strategies according to whether or not the products are constrained by economical delivery lot size.

5 Conclusion

This study discusses two different JIT systems under a global supply chain according to whether the delivery of products is limited to economical lot size. In the future, manufacturers can optimize their total cost by deciding whether or not to cooperate with 3PL' and arrive at their optimal production lot size. The conclusions from these illustrative cases are as follows:

1. The goal to reduce cost in the JIT system under a global supply chain can be attained by setting up economical product delivery strategy according to whether the significance of economical lot size
2. As for upstream manufacturers in the JIT system under global supply chain, they can deliver products to downstream assemblers in JIT system with lower cost through the support of 3PL of fixed quantity-periodic delivery. If the delivery cost of products is strongly affected by the economical delivery lot size and this lot size is much larger than assemblers' demand at a regular interval, the cost effect will be very beneficial.

Approach II in this study seeks ways to resolve operation obstacle in transnational economical delivery lot size and enables the manufacturer to play an aggressive role in the global supply chain. With this trend, 3PL will also occupy a much more important position in the JIT system under a global supply chain.

Appendix A

In Eq. 6, k may be an integer, but in most cases, k is not an integer. Therefore, it is illustrated in two states. In the first state, when k is not an integer, the loading ratio of maximum delivery lot size of products, $\frac{Q_T}{Q_t}$, can be calculated as follows

$$\frac{Q_T}{Q_t} = \frac{\mathrm{rd}}{kd} = \frac{r}{k} = \frac{\lfloor k \rfloor}{k} . \tag{29}$$

In Eq. 29, when k becomes larger, $\frac{Q_T}{Q_t}$ will more closely approach 1, that is, the loading ratio will be higher. After deciding the exact number of shipments reaching optimal cost, M^*, and optimal production lot size, Q_p^*, in approach II, the increased number of shipments per production cycle, AT, can be found when delivered in Q_T not Q_t. Therefore, AT is obtained as follows:

$$AT = \frac{Q_p^*}{Q_T} - \left(\left[\frac{Q_p^*}{Q_t} \right] + 1 \right) . \tag{30}$$

In Eq. 30, the first term, the number of shipments of products delivered in Q_T, is equal to M^*. In the second term, $\left[\frac{Q_p^*}{Q_t} \right] +$ 1, the number of shipments of products delivered in Q_t (e.g., if number of shipments of products delivered in Q_t is 10.8, the exact number of shipments for manufacturers should be 11). In Eq. 21, the optimal production lot size is the production of the optimal number of shipments multiplied by the real delivery lot size, AT will be determined as follows:

$$AT = M^* - \left(\left[\frac{M^* Q_T}{Q_t} \right] + 1 \right) . \tag{31}$$

In Eq. 31, when AT equals zero, it is showed that the number of shipments delivered in Q_T or Q_t are the same in the optimal production lot size (Q_p^*). When AT equals zero, Eq. 31 becomes:

$$M^* = [M^* \frac{Q_T}{Q_t}] + 1 . \tag{32}$$

Because $\frac{Q_T}{Q_t}$ is smaller than 1 ($Q_T < Q_t$) and $\left[M^* \frac{Q_T}{Q_t} \right] < M^* \frac{Q_T}{Q_t}$, therefore,

$$M^* < M^* \frac{Q_T}{Q_t} + 1 . \tag{33}$$

Calculating Eq. 33 and uniting the result with $\frac{Q_T}{Q_t} < 1$ will produce the following equation:

$$1 - \frac{1}{M^*} < \frac{Q_T}{Q_t} < 1 . \tag{34}$$

Eq. 34 is the condition with which manufacturers will not increase number of shipments per cycle delivered in real delivery lot size, Q_T.

In the second state, when k is an integer, Q_T is equal to Q_t. Under this condition, $\frac{Q_T}{Q_t}$ is equal to 1, so the manufacturers' delivery times and 3PL's inventory will not increase. Calculating using Eq. 34 with $\frac{Q_T}{Q_t} = 1$ will produce the following equation:

$$1 - \frac{1}{M^*} < \frac{Q_T}{Q_t} \leq 1 \,. \tag{35}$$

Therefore, approach II is subject to Eq. 26 (Eq. 35).

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