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Modeling stockout risk and JIT purchasing in ready-mixed concrete batching plants

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ABSTRACT

A model for comparing the inventory costs of purchasing under an economic order quantity (EOQ) with a price discount system and a just-in-time (JIT) order purchasing system concluded that JIT purchasing is virtually always the preferable inventory ordering system. This claim however contradicts the practices observed in ready-mixed concrete (RMC) batching plants. By expanding the EOQ model and considering the stockout risks, this paper derives new EOQ-JIT cost indifference point equations. We show that it is possible for an EOQ with a price discount system to be more cost-effective than a JIT system when the stockout risks associated with the JIT purchasing system are high or the annual demand is either too low or too high. The case study conducted in the RMC industry in Chongqing, China supports our proposition.

1. Introduction

Inspired by the success achieved by companies that have adopted the just-in-time (JIT) production policy, others that are still using the economic order quantity (EOQ) purchasing system are pondering whether they should switch to the JIT purchasing system (Wu et al., 2010; Chen et al., 2010; Beheshti, 2010). This is, however, a difficult decision, because there are too many factors that have to be considered. As such, there has been limited research into providing quantitative models for comparing the two systems, especially for scenarios where price discount schemes are available.

Recently, Fazel et al. (1998) developed a series of innovative mathematical models to directly compare the costs between an EOQ with a price discount purchasing system and a JIT purchasing system. While omitting the "fixed costs", such as rental, utilities and personnel salaries from the cost difference function between the EOQ and JIT system, Fazel et al. (1998) EOQ-JIT cost indifference point models showed that JIT was cost-effective only when annual demand was low. In a more recent paper, Schniederjans and Cao (2000) argued that those "fixed costs" items were not fixed and thus should not be left out from the EOQ-JIT cost difference function. Schniederjans and Cao (2000) suggested that in situations where plants adopting the JIT operations could take advantage of physical plant space square meter reduction to include one single cost item, namely, the physical plant space factor, into the EOQ-JIT cost difference function would substantially increase the value of the EOQ-JIT indifference point. Schniederjans and Cao (2000, p. 294) also suggested that there was a "threshold point" for an existing physical plant. The existing physical plant space thus might not be able to hold the substantially increased indifference point's amount of inventory. Hence, additional physical plant space had to be purchased when demand increased. The purchase of additional plant space would again provide one more opportunity for a further round of JIT square foot cost reduction. They then suggested that "… the dynamic nature of a JIT system should continuously achieve a cost advantage over an EOQ system …" and the scenario "… is much like a cat trying to catch its tail …" and therefore concluded that "… a JIT ordering system is preferable to an EOQ system at any level of annual demand and with almost any cost structure" (Schniederjans and Cao, 2000, p. 294). However, they had difficulties to either scientifically or empirically ascertain the capability of an inventory facility to hold the EOQ-JIT cost-indifference point's amount of inventory.

In a recent survey which covered the entire ready-mixed concrete (RMC) industry in Singapore, it was observed that an EOQ system can be more cost-effective than a JIT purchasing

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Nomenclature

JIT	Just-in-time
EOQ	Economic order quantity
Q	The fixed order quantity under an economic order quantity system (unit/order)
h	The annual cost of carrying one unit of inventory in stock under the economic order quantity system ($/year per unit). It excludes the "fixed costs", such as rental, utilities and personnel salaries
k	The cost of placing an order under the economic order quantity system ($/order)
D	The annual demand of an inventory item (units/year)
π_E	A quantity discount rate under the EOQ with a price discount scheme proposed by Fazel et al. (1998)
$Q_{\max}$	The maximum quantity that can be purchased and still receive a quantity discount rate π_E (unit/order)
P_E^0	The purchase price per unit under the EOQ with a price discount approach where the order quantity equals zero ($/unit)
$P_E^{\min}$	The minimum purchase price of an inventory item under the EOQ with a price discount system ($/unit)
TC_E	The so called total annual cost in the classical economic order quantity system ($/year). It excludes the "fixed costs", such as rental, utilities and personnel salaries
H	The expanded annual cost of carrying one unit of inventory in stock under the revised EOQ model ($/year per unit). It includes the "fixed costs", such as rental, utilities and personnel salaries
TC_{Er}	The total annual cost in the revised economical order quantity system ($/year). $TC_{Er} > TC_E$ as the "fixed costs", such as rental, utilities and personnel salaries has been included in TC_{Er}
Q_r^*	The optimum order quantity under the revised EOQ with a price discount system, where the order quantity is below $Q_{\max}$ (unit/order)
Q_r^{**}	The optimum order quantity under the revised EOQ with a price discount system, where the order quantity is above $Q_{\max}$ (unit/order)
P_J	The purchase price per unit under the JIT system ($/unit)
TC_J	The total annual cost using a JIT approach for inventory ordering ($/year) in Fazel et al. (1998)
TC_{Jr}	The revised total annual cost using a JIT approach for inventory ordering ($/year), where stockout risk has been considered
γ	The number of additional working hours that may be affected in a JIT system than that in an EOQ system
β	The value created in one working hour
Z_r	The cost difference between the total costs under the EOQ system and the JIT system
D_{indr1}	The lower EOQ-JIT cost indifference point under the revised EOQ system, order quantity is below $Q_{\max}$
D_{indr2}	The upper EOQ-JIT cost indifference point under the revised EOQ system, order quantity is below $Q_{\max}$
D_{indr1}^{**}	The lower EOQ-JIT cost indifference point under the revised EOQ system, order quantity is above $Q_{\max}$
D_{indr2}^{**}	The upper EOQ-JIT cost indifference point under the revised EOQ system, order quantity is above $Q_{\max}$
N_E	The floor area of an inventory facility under the EOQ system (m^2)
α	The area of the inventory facility space occupied by one unit of inventory item (m^2/unit)
Q_h	The carrying capacity of an inventory facility under the EOQ system (unit)
b	The stock flexibility parameter
Q_{rind}^{**}	The optimal order quantity at the revised EOQ-JIT cost-indifference point, order quantity is above $Q_{\max}$
N_{Eind}	The minimum area of the inventory facility that can accommodate the EOQ-JIT cost indifference point's amount of inventory under the revised EOQ system (m^2)
RMC	Ready mixed concrete
CCA	The Chongqing concrete association
h_f	Facility cost ($/year per ton)
h_r	Land rental cost ($/year per ton)
h_s	Personnel salary ($/year per ton)
h_o	Other holding costs ($/year per ton)

system when the annual demand was extremely high and when the ordering costs cannot be economically split (Wu et al., 2010). In another survey, which covered the entire RMC industry in Chongqing, China, it was found that the JIT purchasing system was not adopted, because the stockout costs associated with JIT purchasing were high. In addition, the models of Fazel et al. (1998) and Schniederjans and Cao (2000) suggested that a JIT purchasing system was always preferred to an EOQ system when annual demand was low. However, prior researchers, such as Tommelein and Li (1999) and Temponi (1995) reported that small companies usually cannot effectively implement JIT purchasing.

1.1. The problems in the existing EOQ-JIT cost indifference point equations

JIT purchasing is not always successful. Many companies are still using the EOQ-based inventory ordering system to purchase their raw materials. This is despite the fact that the plants adopting JIT operation can take advantage of square footage reduction (Wu et al., 2010). The problems experienced by the existing EOQ-JIT cost indifference point equations thus are: (1) Schniederjans and Cao's (2000) models appear to be unable to clearly explain the wide adoption of the EOQ policy in many companies; and (2) none of the models in Fazel et al. (1998) and Schniederjans and Cao (2000) can explain the difficulties in implementing a JIT purchasing policy by small companies. These problems suggest that the real EOQ-JIT cost-indifference point has not yet been derived.

1.2. The reasons

The problems experienced by the existing EOQ-JIT cost indifference point models may arise from two reasons. One reason is that the EOQ with a price discount model, from which Fazel et al. (1998) and Schniederjans and Cao (2000) developed their EOQ-JIT cost difference functions, was based on the Harris (1915) EOQ model. In the Harris (1915) classical EOQ model, some inventory operating costs were assumed to be "fixed". This EOQ with a price discount model is referred to as the classical EOQ with a price discount model in this study, as it incorporates the classical EOQ model and a price discount scheme proposed by Fazel et al. (1998). Another possible reason is that the stockout costs, inherent in JIT purchasing systems, seems to have been mistakenly omitted from the JIT cost function proposed by Fazel et al. (1998). Recent studies, however, suggest that enterprise risks cannot be ignored (Wu and Olson, 2008, 2009a, b; Wu and Olson, 2010a, 2010b, 2010c; Olson and Wu, 2010).

1.3. Research aim

The aim of our study is to derive the alternative formulas for the cost-indifference point between the EOQ system with the price discount scheme proposed by Fazel et al. (1998) and the JIT purchasing system in which stockout costs are considered. This study is an extension of the work of Schniederjans and Cao (2000).

1.4. Structure of the paper

Following the introduction, Section 2 in this paper analyzes the revised total annual cost under the EOQ system. Section 3 analyzes the revised total annual cost under the JIT system. Section 4 derives the revised EOQ-JIT cost indifference point. Section 5 discusses the impact of stockout costs on the selection of the material purchasing system. Section 6 illustrates a case study. Conclusion is stated in Section 7.

2. Revised total annual cost under the EOQ system

h, the annual cost of holding one unit of inventory in stock, is the most subjective components in the classical EOQ model (Chalos, 1992). h often includes the opportunity cost of the working capital tied up in purchased goods, taxes and insurance paid on inventory items, inventory spoilage and obsolescence cost. h excludes the so-called "fixed costs", including "rental, utilities, and personnel salary". Hence, TC_E, "the total annual cost of an inventory item under an EOQ system" in Fazel et al. (1998) was not the actual total annual cost of an inventory item under an EOQ system, which should be the sum of "TC_E" and the "fixed costs".

The so-called "fixed costs", including "rental, utilities, and personnel salary" were excluded from h in the models in Fazel et al. (1998). This was an important assumption made by these researchers when they derived their EOQ-JIT cost-indifference points. However, Gaither (1996) suggested that the annual inventory holding cost should include, in addition to other items, the cost of physical storage. In addition, Wu et al. (2010) and others proved that the so-called "fixed costs" would no longer be constant during JIT operations, and that the saved inventory facilities can be rented out when the annual average inventory level dropped. Then there is a reason to include all components of inventory holding costs into the holding cost item, that is to expand h to be H, when comparing an EOQ system with a JIT system.

When the so-called "fixed costs" is included into the holding cost item, the total cost under the EOQ with a price discount model in Fazel et al. (1998) becomes

$$TC_{Er} = \frac{kD}{Q} + \frac{QH}{2} + (P_E^0 - \pi_E Q)D \quad \text{for} \quad Q \le Q_{\max} \tag{1}$$

$$TC_{Er} = \frac{kD}{Q} + \frac{QH}{2} + P_E^{\min} D \quad \text{for} \quad Q > Q_{\max} \tag{2}$$

where D is the annual demand for the item, Q is the order quantity, k is the order cost, P_E^0 is the purchase price per unit when the order quantity equals zero, π_E is a constant representing the quantity discount rate, $P_E^{\min}$ is the lowest price that the supplier would charge no matter how large the order quantity is, $Q_{\max}$ is the maximum quantity that can be purchased and still receive a quantity discount rate π_E. H is the expanded annual cost of holding one unit of inventory in stock. "H", with the inclusion of the additional inventory holding costs, is thus significantly greater than "h" in the models in Fazel et al. (1998). TC_{Er} is the sum of the inventory ordering cost, the expanded inventory holding cost, and the cost of the purchased units. TC_{Er}, with the inclusion of the so-called "fixed costs", is the actual total cost of the EOQ ordering system. The revised EOQ model assumes that the so-called "fixed costs", including rental, utilities and personnel salary are proportional to the annual average inventory level. This assumption is possible, particularly when the square meter area of an inventory facility is designed in proportion to its annual average inventory level and the rental, utilities and personnel salary are in proportion to the size of the inventory facility. The revised EOQ model is particularly suitable for the scenarios in which the so-called "fixed costs" are adjustable, for example, during the feasibility study stage or design stage of an inventory facility, or the excess inventory facility space can be rented out when the annual average inventory level drops, as observed by Schniederjans and Cao (2000).

By taking the first order derivative with respect to Q in Eq. (1) and setting it to equal to zero, the optimum order quantity under the revised EOQ with a price discount system, Q_r^*, can be derived as

$$Q_r^* = \sqrt{\frac{2kD}{H - 2\pi_E D}} \tag{3}$$

Note that Q_r^* is the optimum order quantity for the revised EOQ system only when $Q_r^* \le Q_{\max}$. When an order quantity is above $Q_{\max}$, the optimum order quantity, Q_r^{**}, can be derived from Eq. (2) and is

$$Q_r^{**} = \sqrt{\frac{2kD}{H}} \tag{4}$$

The revised EOQ model aims to reduce the actual total inventory ordering and holding cost, while the classical EOQ model aims to reduce the sum of the inventory ordering cost and a part of the inventory holding cost. Hence the revised EOQ model is more suitable than the classical EOQ model in representing the total cost under the EOQ system when comparing the EOQ system with the JIT system.

3. Revised total annual cost under the JIT system

JIT purchasing systems are time-sensitive. JIT purchasing requires precise schedules and relies on frequent transportation, as they are generally unable to cope with significant fluctuation in demand. This can be seen in situations arising from the 2011 Tōhoku earthquake and tsunami (Eurasia Review, 2011). The risk parameter, namely the stockout cost, thus should be considered, but was ignored in Fazel et al. (1998) and Schniederjans and Cao (2000). Let $\gamma\beta$ represents the additional stockout costs under a JIT purchasing system compared to that under an EOQ purchasing system, where γ represents the number of additional working hours that may be affected in a JIT system than that in an EOQ system, β represents the value created in one working hour. $\gamma\beta$ is a penalty for using JIT purchasing instead of EOQ purchasing. The total annual cost under the JIT system is therefore revised as

$$TC_{Jr} = P_J D + \gamma\beta \tag{5}$$

where TC_{Jr} is the revised total annual cost under the JIT system, P_J is the unit price under the JIT system, and is greater than P_E^0. This is to partially reflect the holding costs and ordering costs that have been transferred to the materials suppliers (Fazel et al., 1998).

4. Revised EOQ-JIT cost indifference point

The earlier discussion shows that the EOQ with a price discount model can roughly be categorized into two scenarios: the optimal order quantity is below or above $Q_{\max}$. The revised EOQ-JIT cost-indifference points thus will be developed separately for the two scenarios as below.

4.1. Order quantity below Q_{max}

When order quantities are less than Q_{max}, the optimal order quantity for the revised EOQ with a price discount model is governed by Eq. (3). Eq. (3) results in a total annual optimal cost under the EOQ purchasing approach of

$$TC_{Er} = kD\sqrt{\frac{H-2\pi_E D}{2kD}} + \frac{H}{2}\sqrt{\frac{2kD}{H-2\pi_E D}} + \left[P_E^0 - \pi_E\sqrt{\frac{2kD}{H-2\pi_E D}}\right]D \tag{6}$$

Based on Eqs. (5) and (6), the cost difference between the total costs under the EOQ system and the JIT system, Z_r thus can be calculated as

$$Z_r = kD\sqrt{\frac{H-2\pi_E D}{2kD}} + \frac{H}{2}\sqrt{\frac{2kD}{H-2\pi_E D}} + \left[P_E^0 - \pi_E\sqrt{\frac{2kD}{H-2\pi_E D}}\right]D - P_J D - \gamma\beta \tag{7}$$

Eq. (7) is applicable for calculating the cost advantage of using a JIT purchasing system over an EOQ purchasing system, only if the order size in the EOQ system follows the optimal order quantity. Otherwise, the cost advantage of using a JIT purchasing system over an EOQ purchasing system should be calculated as

$$Z_r = \frac{kD}{Q} + \frac{HQ}{2} + (P_E^0 - \pi_E Q)D - P_J D - \gamma\beta \quad \text{for} \quad Q \le Q_{max} \tag{8}$$

Setting Z_r equal to zero, the roots of Eq. (7) are the revised EOQ-JIT cost-indifference points for the scenarios where order quantities are below Q_{max}, D_{indr1} and D_{indr2}, and their values are given by

$$D_{indr1} = \frac{kH - \gamma\beta(P_J - P_E^0) - \sqrt{k^2H^2 - 2kH\gamma\beta(P_J - P_E^0) - 4\pi_E k\gamma^2\beta^2}}{(P_J - P_E^0)^2 + 4\pi_E k} \tag{9}$$

$$D_{indr2} = \frac{kH - \gamma\beta(P_J - P_E^0) + \sqrt{k^2H^2 - 2kH\gamma\beta(P_J - P_E^0) - 4\pi_E k\gamma^2\beta^2}}{(P_J - P_E^0)^2 + 4\pi_E k} \tag{10}$$

4.2. Order quantity above Q_{max}

When order quantities are above Q_{max}, the optimal order quantity for the revised EOQ with a price discount model is governed by Eq. (4), which results in the total annual optimal cost under the EOQ purchasing approach of

$$TC_{Er} = \sqrt{2kDH} + P_E^{min}D \tag{11}$$

The cost difference between the total costs under the EOQ system and the JIT system thus becomes

$$Z_r = \sqrt{2kDH} + P_E^{min}D - P_J D - \gamma\beta \tag{12}$$

Eq. (12) is applicable for calculating the cost advantage of using a JIT purchasing system over an EOQ purchasing system only if the order size in the EOQ system follows the optimal order quantity. Otherwise, the cost advantage of using a JIT purchasing system over an EOQ purchasing system should be calculated as

$$Z_r = \frac{kD}{Q} + \frac{HQ}{2} + P_E^{min}D - P_J D - \gamma\beta \quad \text{for} \quad Q > Q_{max} \tag{13}$$

Setting Z_r equal to zero, the roots of Eq. (12) are the revised EOQ-JIT cost-indifference points for the scenarios where order quantities are above Q_{max}, D^{**}_{indr1} and D^{**}_{indr2}, and their values are given by

$$D^{**}_{indr1} = \frac{kH - (P_J - P_E^{min})\gamma\beta - \sqrt{k^2H^2 - 2kH\gamma\beta(P_J - P_E^{min})}}{(P_J - P_E^{min})^2} \tag{14}$$

$$D^{**}_{indr2} = \frac{kH - (P_J - P_E^{min})\gamma\beta + \sqrt{k^2H^2 - 2kH\gamma\beta(P_J - P_E^{min})}}{(P_J - P_E^{min})^2} \tag{15}$$

5. Discussion

Eqs. (9), (10), (14) and (15) show that the additional stockout costs under a JIT purchasing system, $\gamma\beta$, have significant impact on the selection of the inventory purchasing system. The discussions of the EOQ-JIT cost-indifference points are therefore approached from two angles: (1) $\gamma\beta = 0$ and (2) $\gamma\beta > 0$.

5.1. $\gamma\beta = 0$: Comparing our study with that of Schniederjans and Cao (2000)

Schniederjans and Cao's study focused on the scenario where $\gamma\beta = 0$ and the optimal order quantity is above Q_{max}. When that obtains, D^{**}_{indr1} in Eq. (14) becomes zero. The revised EOQ-JIT cost-indifference point can be calculated by D^{**}_{indr2} in Eq. (15), which becomes $2kH/(P_J - P_E^{min})^2$. The concept of the carrying capacity of an inventory facility can assist to compare the present study with that of Schniederjans and Cao (2000). The "carrying capacity of an inventory facility" is defined as the number of inventory units that can be held by an inventory facility at a specific time. Assuming each unit of an inventory item takes up αm^2 of the inventory facility, the carrying capacity of the inventory facility, Q_h, can be calculated by dividing the number of square meters of the inventory facility, N_E, by the square meters occupied by a unit of inventory, or $N_E/\alpha = Q_h$. To allow for flexibility, the size of the inventory facility, in practice, is usually designed to be greater than the size needed to hold the exact amount of optimal order quantity of inventory. It is reasonable to assume that the size of the inventory facility is b times of the size which carries the optimal order quantity amount of inventory, or $Q_h = bQ_r^{**}$, where b, called the stock flexibility parameter, is greater than or equal to 1. Substituting $Q_h = bQ_r^{**}$ into $N_E/\alpha = Q_h$ would result in $N_E = \alpha bQ_r^{**}$, namely, the formula of the square meter area of an inventory facility which is governed by its optimal order quantity. Substituting $D^{**}_{indr2} = 2kH/(P_J - P_E^{min})^2$ into Eq. (4), the optimal order quantity at the revised EOQ-JIT cost-indifference point, Q^{**}_{rind} can be derived as $Q^{**}_{rind} = 2k/P_J - P_E^{min}$. Substituting Q^{**}_{rind} for Q_r^{**} in $N_E = \alpha bQ_r^{**}$ would result in the minimum square meter area of the inventory facility that can accommodate the EOQ-JIT cost-indifference point's amount of inventory, N_{Eind}, as $N_{Eind} = 2\alpha bk/P_J - P_E^{min}$. Hence, once the inventory space reaches $2\alpha bk/P_J - P_E^{min}$, the physical inventory plant space under the EOQ system can accommodate D^{**}_{indr2} of inventory. The total cost under the EOQ system, where the cost of the physical inventory plant space under the EOQ system has been included, will be equal to the total cost under the JIT system. The cost of the physical inventory plant space under the EOQ system can be balanced by the JIT system. For example, if F represents the annual cost to own and maintain a square meter of physical inventory plant space, $2\alpha bF$ is then a component of H. It seems that Schniederjans and Cao (2000) overlooked that it is possible for an inventory facility to hold the EOQ-JIT cost-indifference point's amount of inventory, once the square meters of an inventory facility reached N_{Eind}. Hence, another expression of this finding is that for scenarios in which the optimal order quantity is above Q_{max}, an EOQ-based system can be more cost-effective than a JIT system when the size of the inventory facility is above N_{Eind}.

5.2. $\gamma\beta > 0$

For $\gamma\beta > 0$, there are two scenarios where the optimal order quantity is below or above Q_{max}, and are discussed below.

5.2.1. The optimal order quantity is below Q_{max}

Comparing Eq. (9) and (10), it can be found that the condition for the revised EOQ-JIT cost-indifference points, D_{indr1} and D_{indr2}, to be real numbers is for $\lambda\beta$ to be below a specific value $(\gamma\beta)_{limit}$, or

$$\gamma\beta \le (\gamma\beta)_{limit} = \frac{H\sqrt{(P_J - P_E^0)^2 + 4\pi_E k} - H(P_J - P_E^0)}{4\pi_E} \tag{16}$$

When the additional stockout costs under a JIT purchasing system are above $(\gamma\beta)_{limit}$, an EOQ system is preferable to a JIT purchasing system. When the additional stockout costs of a JIT purchasing system are below $(\gamma\beta)_{limit}$, an EOQ system is still preferred to a JIT purchasing system for an annual demand below D_{indr1}. Tommelein and Li (1999) and Temponi (1995) observed that small companies usually had difficulties in implementing JIT purchasing. It appears that the annual demand of these small companies probably fell in the interval $(0,D_{indr1})$.

5.2.2. The optimal order quantity is above $Q_{\max}$

When the optimal order quantity is above $Q_{\max}$, the EOQ-JIT cost difference function of Eq. (12) can be rewritten as

$$Z_r = -\left\{\left[\frac{\sqrt{kH}}{\sqrt{2(P_J-P_E^{\min})}} - \sqrt{(P_J-P_E^{\min})D}\right]^2\right\} + \left[\frac{kH}{2(P_J-P_E^{\min})} - \gamma\beta\right] \tag{17}$$

The first term on the right hand side of Eq. (17) is always negative. When the additional stockout costs of a JIT system are above $kH/2(P_J-P_E^{\min})$, Z_r is always negative; an EOQ system is thus always preferable to a JIT system. When the additional stockout costs of a JIT system are below $kH/2(P_J-P_E^{\min})$, an EOQ system can still be more cost-effective than a JIT system if the annual demand of this inventory item is greater than D^{**}_{indr2}.

The impact of the additional stockout costs under a JIT purchasing system, $\gamma\beta$, on the adoption of an appropriate purchasing system is further illustrated by a case study from one RMC supplier in Chongqing.

6. A case study

Ready mixed concrete (RMC) is a product that is widely used in the construction industry. The production of RMC is a highly repetitive manufacturing process. Sand, one of the raw materials of RMC, may be purchased by using either the EOQ system (Tommelein and Li, 1999) or the JIT system (Wu et al., 2010). To understand the procurement systems of sand adopted by the RMC suppliers in Chongqing, a survey and intensive site studies were conducted by the authors (Wu et al., 2010). The survey covered all the twenty registered members of the Chongqing Concrete Association (CCA), and showed that among all the RMC suppliers surveyed, almost all have built their own large sand yards and procured their sand in an EOQ-based system, as traffic jams were common in that city.

6.1. RMC supplier L in Chongqing

Most of the sand consumed in the Chongqing RMC industry was purchased from quarries along the Yangtze River or Jialingjiang River. RMC supplier L in Chongqing (Wu et al., 2010) was using an EOQ system to procure sand. This RMC supplier usually had 5–6 sand suppliers. The quarries of these sand suppliers were mainly located along the Jialingjiang River. The sand yard owned by supplier L was about 600 m^2. RMC supplier L usually raised an order approximately twice a month for about 2,000 t of sand. The carrying capacity of the sand yard was also about 2,000 t. Stock flexibility parameter was $b=1.5$. The carrying capacity in this case study was determined by the routine inventory order size, rather than the optimal order quantity of sand. This will be explained later. The annual sand demand of RMC supplier L in 2003 was $D=55{,}000$ t. The sand suppliers offered a few alternative pricing strategies. One of the pricing strategies offered was as follows. The delivery price started at $P_E^O=¥21$/ton (One Chinese Yuan= 0.15 US Dollars). For every additional ton ordered, the price would decrease by $\pi_E=1.0\times10^{-3}$ RMB for the entire order lot. The discount was valid for an order quantity up to $Q_{\max}=1{,}000$ t, when the price per unit became $P_E^{\min}=¥20$/ton. Beyond that level, the price remains the same. The annual cost of holding one ton of cement was $H=¥\,61$/year per ton. The holding cost can be broken down into h_f, facility cost; h_r, land rental cost; h_s, personnel salary; and h_o, other holding costs. The facility cost was the depreciation and operating cost of the facilities to unload, upload and shift sand between the sand yard and sand bins in the RMC batching plant, with $h_f=¥\,42$/year per ton. The face-shovel was the typical sand loading facility. The land rental cost was $h_r=¥9$/year/ton. The personnel salary cost was $h_s=¥5$/year/ton. The other holding costs were $h_o=¥5$/year/ton, which included utilities, property tax, insurance, sand spoilage cost, and the opportunity cost of the working capital tied up in purchased sand. The cost of placing an order was $k=¥30{,}000$/order for transportation alone. Each ton of sand took up $\alpha=0.2$ m^2/t sand yard. The annual cost to rent a square meter of inventory facility was $F=¥\,15$/year/m^2. If sand was purchased under a JIT system, the cost was $P_J=¥36$/ton. To ensure the workability of concrete and the integrity of the structure, RMC concreting usually has a strict requirement on RMC supply. A contractor usually concurrently signs contracts with more than one RMC supplier. The contractor may order its RMC from another RMC supplier, if a RMC supplier cannot mix the ordered RMC on time. Hence, the hourly loss of a RMC batching plant is the product of the after-tax profit of producing one cubic meter of RMC and the batching capacity of the RMC batching plant (in cubic meters). The after-tax profit of producing one cubic meter of RMC was ¥35/m^3. The batching capacity of RMC supplier L was 60 m^3/h. The hourly loss of RMC supplier L, thus, was $\beta=¥$ 2100/h. The number of working hours that may be lost due to ordering sand in a JIT pattern was estimated to be $\gamma=20$ h/year. It is essential to note that the data for this case study were collected by interviewing the production manager and the customer service supervisor of RMC supplier L. These data are real-life data and are unlike those demonstrated in the hypothetical examples given by Schniederjans and Cao (2000, p. 291). The routine sand order size was above $Q_{\max}$, and Eq. (4) was therefore suitable for calculating the optimal order quantity. Based on Eq. (4), the optimal order quantity Q_r^* was expected to be 7355 t/order. The usual sand order quantity was, however, around 2,000 t/order. Hence the cost difference between the EOQ and the JIT purchasing system cannot be worked out by Eq. (12), as the sand was not ordered at its optimal order quantity. Nevertheless, Eq. (13) can be used to calculate the cost advantage of using a JIT purchasing system over an EOQ purchasing system. According to Eq. (13), the cost advantage of using a JIT purchasing system over an EOQ purchasing system was $¥-36{,}000$/year. Hence, all the sand consumed by RMC supplier L was not ordered in a JIT fashion. The average daily demand of the sand was only about 150 t. RMC supplier L, however, usually kept 3000 t of sand in its sand yard. A similar field study conducted at the same time in land-scarce Singapore suggested that the sand buffer stock in a JIT RMC batching plant, with the same production capacity, namely, 60 m^3/h, was usually about 200 t, about 1/15th that of the batching plant in Company L in Chongqing (Wu et al., 2010).

6.2. Oder splitting

It is interesting to note that the order quantity of sand by RMC supplier L was significantly below its optimal order quantity. Pan and Liao (1989) proved that order splitting can reduce the total annual cost under an EOQ system, when assuming order splitting does not increase order cost. As stated earlier, the quarries for supplying sand for RMC supplier L were located along the Jialingjiang River, which was less than 100 km away from RMC supplier L. Sand can be transported by various barges with capacities arranged from 100 t to 2000 t. Order splitting did not significantly increase the ordering costs. Hence, the order quantity of RMC supplier L was not the optimal order quantity derived from Eq. (4). Consequently, the square meter area of the sand yard was determined by its routine order size, rather than its optimal order quantity. It seems that RMC supplier L was unintentionally practicing order splitting for procurement of its sand. However, RMC supplier L cannot adopt a JIT purchasing system and still had to pay for a large sand yard, as the additional stockout costs of the JIT purchasing system were too high.

The case study demonstrates that the stockout costs have a significant impact on the adoption of an appropriate inventory purchasing system, and that JIT may not always be preferred over an EOQ system.

7. Conclusion

The models in Schniederjans and Cao (2000) suggested that a JIT purchasing system is always more cost-effective than an EOQ purchasing system when JIT purchasing can take advantage of physical plant space reduction. This claim however contradicts practices observed in the industries. By expanding the classical EOQ model and considering stockout risk, we developed new EOQ-JIT cost indifference point models. The formulas of the revised EOQ-JIT cost-indifference point, together with our theoretical analysis, show that by including the "physical plant space" factor, as well as all other factors which were omitted by Fazel et al. (1998), it is still possible for an EOQ with a price discount system to be more cost-effective than a JIT purchasing system when annual demand are high enough. The case study from the RMC industry in Chongqing, China showed that JIT purchasing is not cost effective, particularly when the stockout risks associated with the JIT purchasing system are high. Our models also explained in theory why small firms have difficulties in implementing JIT purchasing. The revised EOQ model assumes that the "fixed" inventory operating costs including rental, utilities and personnel salary are adjustable. Hence, our models are particularly useful when the "fixed" inventory operating costs are adjustable, for example, during the feasibility study stage or design stage of an inventory facility, or for scenarios in which the redundant inventory facility can be rented out when the annual average inventory level goes down, as observed by Schniederjans and Cao (2000).

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