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Negotiation Model for Optimal Replenishment Planning Considering Defects under the VMI and JIT Environment

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ABSTRACT

As the supply chain becomes more complicated and globalized, outsourcing techniques, such as the Vendor Managed Inventory (VMI) under the Just-In-Time (JIT) conditions, are becoming widely adopted, in order to reduce inventory, lead-time and set up costs. For vendors, Third Party Logistics (TPL) is regarded as one of the best alternatives used to improve both their service level and profit. For TPL service providers, their profits must be maximized under economies of scale. However, under the JIT condition, it is very difficult to balance the order quantity whilst satisfying the predefined conditions related to inventory level. In addition, while transporting and keeping items, the exposition to various risk factors is likely. In this paper, we propose the TPL service provider to determine the optimal order quantity, considering defective items under the VMI and JIT conditions. By designing a mathematical decision-making problem based on the EPQ (Economic Production Quantity)/EOQ (Economic Order Quantity) with defective items, we can find the optimal order quantity for TPL service providers under VMI and JIT. With illustrative numerical examples, the procedure and the impacts of the expected defective rates are explained with sensitivity analysis.

1. Introduction

The current global business environment is rapidly changing with global financial instability, the widely adopted Just-In-Time (JIT) outsourcing strategy, advances in technologies, e-business and a shorter time-to-market. Therefore, it forces organizations to design and adopt new ways of doing business, such as integrating global supply chains (Stefanovic et al., 2009). However, as the supply chains are globalized and integrated, they become more vulnerable as they are exposed to natural, as well as man-made, risk factors. Vulnerability is generally

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defined as an exposure to serious disturbance arising from risks within the supply chains, as well as risks external to the supply chains (Christopher and Peck, 2004). The greater uncertainties in supply and demand, the globalization of the market, the shorter product and technology life cycles, and the increased use of manufacturing, distribution and logistics partners all result in complex international supply network relationships. This has led to higher exposure to risks in the supply chain (Christopher et. al., 2002).

In order to cope with these challenges, various strategies have been suggested, such as VMI (Vendor Managed Inventory) and TPL (Third Party Logistics) with their integration to JIT. Under VMI, the vendor or supplier is given the responsibility of managing the customer's stock. For clarity, the terms 'distributor' for the customer and 'manufacturer' for the supplier or vendor in the VMI relationship will be used. VMI is based on information sharing of the supply process using information technology and many forms of derived VMI, such as QR (Quick Response), SCR (Synchronized Consumer Response), CR (Continuous Replenishment) and ECR (Efficient Consumer Response). The new strategies, which integrate VMI and JIT, have been designed to reduce the negative impacts from the bullwhip-effect. However, this has led to an increase in responsibility for vendors (Disney and Towill, 2003).

As a result, even small vendors are asked to secure a quick response system under JIT and VMI conditions. Moreover, they are asked to improve quality, which requires high costs, as well as long-time research and development (R&D) projects. If vendors cannot satisfy the prearranged requirements, such as lead time and number of defects, they will be charged the penalty. This reduces the profit of vendors. However, most of the research has focused on maximizing the buyer's profit by designing a contract with vendors.

TPL is regarded as one of the best alternatives for vendors to improve both their service level and profit at the same time. For the first time, the TPL service has emerged from the demand for a very advanced logistics service. Clients usually adopt the TPL strategy to enhance their own business performance, such as lead-time and customer responsiveness. In addition, they can apply TPL to enter the new market by utilizing service provider assets, such as warehouses, transportation networks, human resources, information systems and knowledge on the new market, including how to control the inventory level (Hertz and Alfredsson, 2003).

The most important task that VMI clients with ask for to the TPL service provider is how to manage the inventory level considering market demand, lead time for transportation, and the quality of incoming lot at the same time. Salameh and Jaber (2000) developed an economic order quantity (EOQ) model under random yield, whereby each order contains a random fraction of imperfect quality items with a known probability distribution. Limited research, such as Maddah and Jaber (2008), has been proposed by extending the EOQ models (Salameh and Jaber, 2000). In particular, the extension of the EPQ (Economic Production Quantity) model has been suggested by considering TPL service providers' view under the VMI and JIT constraints.

The remainder of this paper is organized as follows. In Section 2, we explain the basic concepts and objectives of the JIT, VMI and TPL service. Also, how to extend the EPQ and EOQ defective models presented by Salameh and Jaber (2000) is introduced. In Section 3, the procedure to obtain the optimal order quantity for TPL under the JIT and VMI environment is presented. In Section 4, the procedure is illustrated with numerical examples and the impacts of order quantity on the total cost are reviewed with sensitivity analysis. Finally, Section 5 concludes the work.

2. Literature Review

2.1. *JIT and VMI systems*

Since its introduction in the 1950s, JIT has been regarded as the most general and widely accepted production strategy for global manufacturing companies. Brox and Fader (1997) showed that the JIT strategy can guarantee a better cost-efficiency. This is supported by: (1) the fact that, in most case, the elasticity calculated from the two groups of firms, buyers and vendors, are significantly different; (2) the cost elasticity with respect to output is lower for the JIT firms than for the non-JIT firms, indicating that they are better able to capture economies of scale and density; (3) the difference between the elasticity of factor productivity, with respect to output changes, shows the JIT firm as being more labor and materials saving than the non-JIT firms. In addition, the benefits of the JIT strategy not only include lead-time reduction but also other performance indicators, such as setup cost reduction and quality improvement (Ouyang, Chen and Chang, 2002). Aghazadeh (2003) mentioned that JIT may guarantee the benefits from applying JIT such as cost reduction, total quality management (TQM) initiatives related to the supply, quality and human resources.

In order to enjoy the benefits from JIT, it requires very tough preconditions, in particular, the relationship with vendors in order to achieve the essential goal of JIT. For example, the successful implementation of JIT requires single sourcing, the location of close suppliers, long-term relationships, collaborative planning and scheduling, frequent deliveries of small lot sizes and stable supply-chain pipelines. Contrary to the great benefits of buyers, these preconditions expose suppliers to the risks and uncertainties of the supply chain due to frequent purchasing orders, variance in volume, consolidated shipments, exchange rates, customs clearance processes and tariffs (Das and Handfield, 1997).

2.2. *VMI with JIT*

The APICS Dictionary (10th edition, 2002) defines VMI as "a means of optimizing supply chain performance in which the supplier has access to the customer's inventory data and is responsible for maintaining the inventory level required by the customer". Kevin O'Brien (2004) has extended the concepts of the VMI operation process and business conditions. VMI can be understood as the strategy to keep the vendor-owned inventory in the buyer's facility. Ownership of the inventory is typically presumed to transfer from the supplier to the buyer at the time the inventory is removed from the inventory. As with the preconditions of JIT systems, vendors are required to secure the real-time inventory monitoring and demand management system, whereby buyers and vendors can make decision on replenishments (Mateen and Chatterjee, 2015). Currently, buyers ask TPL service providers for the VMI service in order to enhance the service level while they focus on their own competencies. Coping with the demand of the VMI service, TPL service providers should re-design their own global logistics network and operation processes in their own warehouse (Vaidyanathan, 2005). Benefits can be expected with the applications of VMI systems with the economies of scale with high order quantities. However, it is contradictive to the basic characteristics of JIT, requiring more frequent purchasing order with variable and relatively small lot size.

2.3. *EPQ/EOQ models considering defects*

In traditional EOQ and EPQ models, it is assumed that all incoming lots do not have defects. However, this is very distinct from the practical business environment. No vendors can guarantee perfect quality, even if they have a perfect pre-screening process before product delivery. Hong and Hayya (1992) extend and generalize the model designed by Porteus (1986), which includes a budget constraint, a continuous quality improvement process and a setup cost reduction. They suggest the deterministic order-splitting EOQ model, which assumes that the aggregated ordering cost, which includes transportation, inspection, as well as any other costs incurred by order splitting, a non-decreasing function of the number of deliveries.

David and Eben-Chaime (2003) attempt to identify the degree of independence and level of flexibility in terms of lot sizing and delivery scheduling in a single-vendor and single-buyer system. Yang and Pan (2004) presented an integrated model to minimize the sum of the ordering/setup cost, holding cost, quality improvement investment and crashing cost by simultaneously optimizing the order quantity, lead-time, process quality and number of deliveries with a normal lead-time demand probability distribution. Kim et al., (2007) suggested a procedure for coordinating the inventory replenishment, production and shipping decisions for a single producer with multiple customers and suppliers. Salameh and Jaber (2000) developed an extended EOQ model where imperfect quality items are salvaged at a discount price. Previous research assumes imperfect production processes that generate defects which are either reworked or scrapped. Incoming lots of raw material containing items of imperfect quality that occur as a random fraction with a known probability distribution, undergo a screening in which defective items in the lot are removed by the end of the screening period and sold at a discounted price. Several studies have extended this model (Khan et al., 2011).

Fazal (1997) developed a mathematical model that compares the traditional EOQ model with JIT, and determines the point of cost indifference between the two systems. For JIT purchasing, many studies emphasize the quality of the purchased products as a successful factor of JIT purchasing. Therefore, Kuo (2005) expand the comparative Fazal's model to include the cost or penalty of products with imperfect quality.

Screening time is one of the major issues identified in previous research related to defective products. With a full quality inspection strategy, it is possible to remove the screening process and prevent the delivery of defective items. Bazan et al., (2014) consider a vendor-buyer supply chain operating a VMI with a CS agreement and a vendor`s production process that is imperfect. They extended the model of Braglia and Zavanella (2003) by assuming that the vendor guarantees the full inspection on their production process and defective items are scrapped and/or reworked. Maddah and Jaber (2008) assume that received orders are subject to a full inspection and that items of imperfect quality are kept in stock until the end of the screening process, when they are sold as a single batch at a reduced price. They derive an expression for the optimal order quantity that maximizes retailer`s profit.

However, there exist limitations when applying the VMI environment to a JIT system. Vendors are responsible for the defective items. They should keep a greater inventory than expected, as well as accept the additional costs that correspond to the defective items, such as recovery, shortage, and backorder. In this paper, the EPQ/EOQ model is extended for defective items, while considering the decision-making procedure for vendors as VMI service providers with JIT conditions.

3. Basic and Proposed Models

3.1. *Basic EPQ/EOQ model considering defective items*

In order to describe the basic extended EPQ/EOQ model considering the defective items, all notations are summarized and explained in Table 1.

Table 1
Notation and short explanations

D	Contracted demand between vendor and buyer
n	Batch size from vendor to TPL
$\boldsymbol{p}$	Expected defective value for vendor for each production (the previous '$\boldsymbol{a_V}$' influences the production of the next batch 'p`, where, $\boldsymbol{a_V} = \boldsymbol{p}$`)
A	Actual defective rate after full inspection, where, $A = a_V + a_T - a_V a_T$, $(0 \le A \le 1)$
$\boldsymbol{a_V}$	Generated defective rate by vendor
$\boldsymbol{a_T}$	Generated defective rate by TPL
$\boldsymbol{d_{JIT}}$	Average quantity for JIT delivery from TPL to manufacturer
$\boldsymbol{C_h}$	TPL unit holding cost
$\boldsymbol{C_{d1}}$	TPL unit delivery cost from vendor to TPL
$\boldsymbol{C_{d2}}$	TPL unit delivery cost from TPL to manufacturer
$\boldsymbol{C_i}$	TPL unit inspection cost
$\boldsymbol{C_s}$	TPL unit disposal cost
$\boldsymbol{C_r}$	Unit reorder cost, if $(A - p \le 0)$, then $(C_r = 0)$
T	Response duration of TPL per batch

Salameh and Jaber (2000) developed an inventory model which accounted for imperfect quality items using the EPQ/EOQ formulae (Sana, 2011). This was first model that provided an EOQ for a buyer who receives an imperfect batch. They extended the traditional EOQ model by accounting for imperfect quality items under the following assumptions: (1) the demand is deterministic, (2) the orders are replenished instantaneously, (3) the lot contains a fixed fraction 'p' of defectives with a known probability density function, (4) screening is performed to separate these defective items, and (5) the defective items are sold as a single batch at a discounted price. The inventory profile for this model is illustrated in Fig. 1. (Khan et al., 2011).

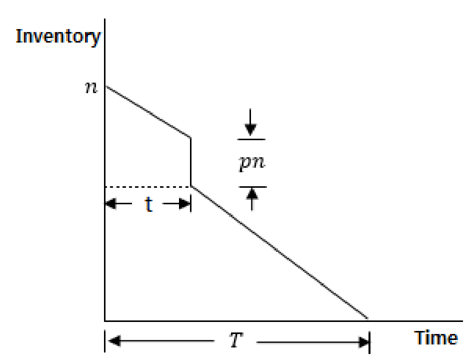

Fig. 1. The inventory level considering the defective items

In Fig. 1, n represents the lot size, p is the ratio of imperfect quality items, D is the demand rate, t is the screening time, and T is the cycle time. To prevent shortages, Salameh and Jaber (2000) adopted the condition as described in equation (1):

$$E[n, p] \ \geq \ Dt. \tag{1}$$

Under this condition, the inventory cycle time can be obtained as follows:

$$T = \frac{(1-\mathrm{p})\mathrm{n}}{D}. \tag{2}$$

Therefore, the total cost within a single inventory cycle is concluded as equation (3).

$$\mathrm{TC(n)} = \mathrm{K} + cn + dn + h\left\{\frac{n(1-\mathrm{p})T}{2} + \frac{\mathrm{p}\,n^2}{x}\right\}, \tag{3}$$

where K is the order cost, p is the unit purchase price, d is the unit screen cost, h is unit holding cost, and x is the screening rate (x > D). The total profit per cycle time can be obtained as equation (4).

$$\mathrm{TP(n)} = \mathrm{sn(1-p) + vnp} - \left[\mathrm{K} + cn + dn + h\left\{\frac{n(1-\mathrm{p})\mathrm{T}}{2} + \frac{\mathrm{p}n^2}{x}\right\}\right], \tag{4}$$

where s and v are the selling and salvage prices, respectively. The expected total profit per unit time function is computed as in equation (5).

$$\mathrm{E[TPU(n)]} = \mathrm{E}\left[\frac{TP(n)}{T}\right], \tag{5}$$

or, as in equation (6).

$$\mathrm{E[TPU(n)]} = \mathrm{D}\left(s - \mathrm{v} + \frac{hn}{x}\right) + D\left(v - \frac{hn}{x} - p - d - \frac{K}{n}\right)E\left[\frac{1}{1-P}\right] - \frac{hn(1-E[P])}{2}. \tag{6}$$

The optimal order quantity, n^*, that maximizes can be obtained as follows:

$$n^* = \sqrt{\frac{2KDE\left[\frac{1}{(1-P)}\right]}{h\left[1 - E[P] - \frac{2D\left(1-E\left[\frac{1}{1-P}\right]\right)}{x}\right]}}. \tag{7}$$

The model defined by equation (7) is hence referred to as the modified EOQ model for imperfect items.

3.2. *Basic assumptions and transaction model*

The ultimate goal of this research is to find the optimal order quantity considering the defective items for the TPL service provider under the VMI and JIT environment. The transaction among vendors, manufacturers and TPL is described in Fig. 2. It includes the flow of materials and information and responsibilities of all participants.

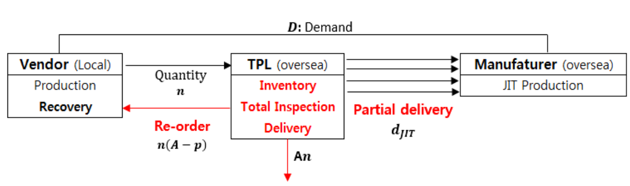

Fig 2. The basic transaction model

The demand is determined based on the contract between the vendor and the manufacturer. When the vendor distributes a lot with the quantity 'n' and defective rate, 'p', to TPL after sampling inspection, the expected quantity of the delivered lot becomes 'd_{JIT}' which is generally less than n ($d_{JIT} < n$). Also, the TPL should inform to the vendor about the number of the defective items as soon as the total quality inspection is finished. If the actual defective rate is higher than the expected rate (A > p), TPL should immediately reorder the shortage quantity to the vendor. The separated defectives should be disposed. In order to build the proposed transaction model, the following is assumed:

- The vendor has an infinite production capacity.
- TPL finishes the full inspection before delivering to the manufacturer.
- There are no defective items in the lot which are delivered from TPL to the manufacturer.
- TPL can place a re-order to the vendor equal to the amount of the defective items after disposing of them.
- It is possible to clarify who is responsible for the defective items between the vendor and TPL.

3.3. *Mathematical model for TPL decision making*

Under the contract with vendors, TPL should determine the optimal quantity ($\boldsymbol{n^{TPL}}$) to minimize the total cost. In this section, the procedure used to devise the total cost function of TPL is explained, and the optimal order quantity is calculated. According to the basic transaction model and assumptions, the total cost for TPL can be obtained as follows:

$$\begin{aligned}\mathrm{TC(n)} = \text{holding cost} - \text{delivery cost} - \text{inspection cost} \\ - \text{disposal cost} - \text{reorder cost}\end{aligned} \tag{8}$$

In summary, the amount of the order quantity is dependent on the production rate and the demand of the manufacturer. However, TPL should adjust the order quantity considering the defective items due to the imperfect inspection by the vendor and the risk of damage or loss while transportation and storage during TPL operations. As it is assumed that TPL has the full inspection, TPL can inform the vendor of the actual defective rate. The vendor can then adjust the production rate for the next batch without the screening time (t). The inventory of TPL is illustrated in Fig. 3.

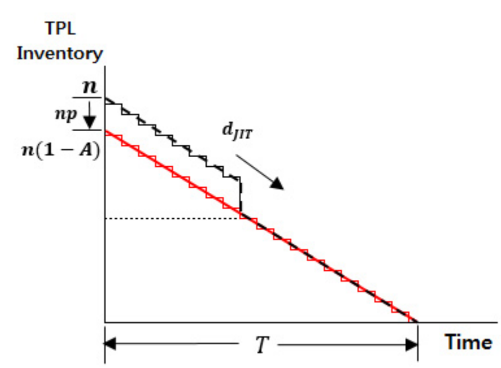

Fig 3. The effect of the full quality inspection

The actual defective rate is used to calculate the total costs of TPL. The reorder cost is generated when the actual rate is higher than the expected rate. The following equations detail the calculations of the costs.

$$\text{Holding Cost(n)} = \frac{n(1-A)C_h}{2}, \tag{9}$$

$$\text{Delivery Cost(n)} = \frac{D}{n}C_{d1} + \frac{n(1-A)}{d_{JIT}}C_{d2}, \tag{10}$$

$$\text{Inspection Cost(n)} = \mathrm{n}C_i, \tag{11}$$

$$\text{Disposal Cost(n)} = AnC_s, \tag{12}$$

$$\text{Reorder Cost(n)} = n(A-p)C_r. \tag{13}$$

The total cost per single batch can be obtained as follows:

$$\mathrm{TC(n)} = \frac{n(1-A)}{2}C_h + \frac{D}{n}C_{d1} + \frac{n(1-A)}{d_{JIT}}C_{d2} + nC_i + AnC_s + n(A-p)C_r, \tag{14}$$

The convexity of the expected total cost function, as a minimum condition, is described by the first derivatives of equation (14) as follows:

$$\mathrm{TC'(n)} = \frac{(1-A)}{2}C_h - \frac{2D}{n^2}C_{d1} + \frac{(1-A)}{d_{JIT}}C_{d2} + C_i + AC_s + (A-p)C_r, \tag{15}$$

The second derivative of equation (14), $\mathrm{TC''(n)} = \frac{6D}{n^3}C_{d1} \geq 0$, is positive for all values of n. This implies that there exists a unique value n^{TPL} that minimizes equation (14), and it is given as:

$$\boldsymbol{n^{TPL}} = \sqrt{\frac{4DC_{d1}d_{JIT}}{2(1-A)C_{d2} + d_{JIT}\{(1-A)C_h + 2C_i + 2AC_s + 2(A-p)C_r\}}}. \tag{16}$$

This result allows vendor to change the next production quantity by revising the defective rate based on the actual defective rate, A. Also, to guarantee the existence of the optimal order quantity, $\boldsymbol{n^{TPL}}$, the following condition in equation (17) should be satisfied:

$$|2(1-A)C_{d2} + d_{JIT}\{(1-A)C_h + 2C_i + 2AC_s\}| > |2d_{JIT}(A-p)C_r|. \tag{17}$$

4. Numerical example

To illustrate the proposed model, the simple numerical example is described. Table 2 presents the parameters used in the example and their values.

Table 2

Parameters and values

Parameters	Values	Parameters	Values
D	1,000,000 units	C_{d1}	\$ 0.8 /unit
d_{JIT}	10 unit/one time	C_{d2}	\$ 0.3 /unit
p	0.02	C_i	\$ 0.03 /unit
C_h	\$ 3 /unit	C_s	\$ 1 /unit
		C_r	\$ 0.1 /unit

The value of the actual defective rate (A) after the full inspection is obtained by equation (18), considering the random variables for vendor (a_V) and TPL (a_T), as well as their probability density functions, $f(a_T)$ and $f(a_V)$.

$$\mathrm{A} = \mathrm{E}[a_V] + E[a_T] - E[a_V] \times E[a_T], (0 \leq \mathrm{A} \leq 1). \tag{18}$$

According to the assumption and basic transaction model, both expected values of the random variables can be obtained using the following equations:

$$\mathrm{f}(a_V) = \begin{cases} 50, 0 \leq a_V \leq 0.02 \\ 0, \quad otherwise \end{cases} \quad \mathrm{E}[a_V] = \int_0^{0.02} 50a_V da_v = 0.01, \tag{19}$$

$$\mathrm{f}(a_V) = \begin{cases} 50, \quad 0 \leq a_V \leq 0.02 \\ 0, \quad otherwise \end{cases} \quad \mathrm{E}[a_V] = \int_0^{0.02} 50a_V da_v = 0.01. \tag{20}$$

From equation (18), the value of the actual defective rate (A) can be obtained as in equation (21).

$$\mathbf{A} = 0.01 + 0.01 - (0.01 \times 0.01) = 0.0199. \tag{21}$$

Finally, we derive the optimal order quantity for TPL, (n^{TPL}) as 1,106 by using equation (16). Under the same conditions, the optimal order quantity (n^*) is equal to 5,802 units based on equation (7), following the extended EOQ/EPQ model proposed by Salameh and Jaber (2000).

To evaluate the impact of the parameters, the results of the sensitivity analysis of the proposed model are presented in Table 3.

Table 3

Result of sensitivity analysis

a_V	a_T	A	n^{TPL}	TC	Recovery Quantity (RQ)	RQ of Vendor	RQ of TPL
0.000	0.000	0.0000	1013	2368	0	0	0
0.000	0.005	0.0050	1014	2366	0	0	0
0.000	0.010	0.0100	1014	2365	0	0	0
0.000	0.020	0.0200	1016	2362	0	0	0
0.000	0.025	0.0250	1017	2360	5	0	5
0.000	0.030	0.0300	1018	2358	10	0	10
0.000	0.035	0.0350	1018	2357	15	0	15
0.000	0.040	0.0400	1019	2355	20	0	20
0.000	0.045	0.0450	1020	2354	25	0	25
0.010	0.000	0.0100	1014	2365	0	0	0
0.010	0.005	0.0150	1015	2363	0	0	0
0.010	0.010	0.0199	1016	2362	0	0	0
0.010	0.020	0.0298	1018	2359	10	0	10
0.010	0.025	0.0348	1018	2357	15	0	15
0.010	0.030	0.0397	1019	2355	20	0	20
0.010	0.035	0.0447	1020	2354	25	0	25
0.010	0.040	0.0496	1020	2352	30	0	30
0.010	0.045	0.0546	1021	2350	35	0	35
0.020	0.000	0.0200	1016	2362	0	0	0
0.020	0.005	0.0249	1017	2360	5	0	5
0.020	0.010	0.0298	1018	2359	10	0	10
0.020	0.020	0.0396	1019	2355	20	0	20
0.020	0.025	0.0445	1020	2354	25	0	25
0.020	0.030	0.0494	1020	2352	30	0	30
0.020	0.035	0.0543	1021	2350	35	0	35
0.020	0.040	0.0592	1022	2349	40	0	40
0.020	0.045	0.0641	1022	2347	45	0	45
0.030	0.000	0.0300	1018	2358	10	10	0
0.030	0.005	0.0349	1018	2357	15	10	5
0.030	0.010	0.0397	1019	2355	20	10	10
0.030	0.020	0.0494	1020	2352	30	10	20
0.030	0.025	0.0543	1021	2350	35	10	25
0.030	0.030	0.0591	1022	2349	40	10	30
0.030	0.035	0.0640	1022	2347	45	10	35
0.030	0.040	0.0688	1023	2346	50	10	40
0.030	0.045	0.0737	1024	2344	55	10	45

The total cost is inversely proportional to the actual defective rate (A) and the optimal quantity for TPL (n^{TPL}). The results prove that TPL may order just 1,016 units with the minimum cost of 2,362, without any costs from shortages. Fig. 4 illustrates the relationship between the optimal quantity (n^{TPL}) and the recovery quantity of TPL (RQ of TPL). The optimal order quantity increases gradually, although the recovery quantity of TPL (straight line) and the trend (dotted line) increase more sharply.

The results of the sensitivity analysis imply that TPL should place more weight on the defective items that are transported from the vendor as these cause additional costs. In addition, although the actual defective rate and the delivery quantity decrease, they do not have a great impact on the total cost.

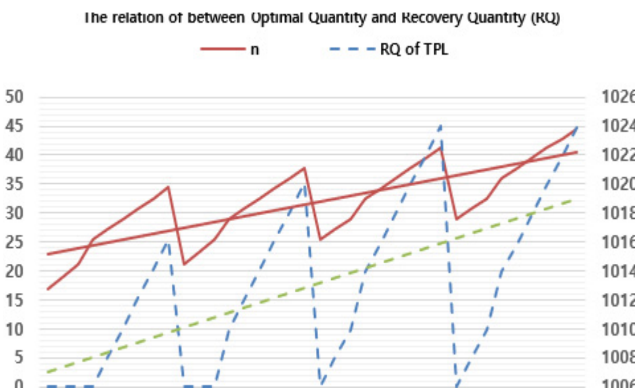

Fig 4. The relationship between Optimal Quantity and Recovery Quantity.

5. Conclusions

As the supply chain becomes more complicated and globalized, buyers increasingly move to outsourcing strategies. These strategies are integrated with advanced strategies such as VMI, which reinforce the right and responsibility of suppliers. However, buyers still implement the JIT policy, even though they extend the boundary of collaboration. It makes vendors find the advanced alternatives which they can keep their own profit. The most representative alternative is the TPL service, which can control the inventory level of buyers. For the TPL service provider, their profit must be maximized under economies of scale. However, under the JIT condition, it is very difficult to balance the order quantity while satisfying the predefined conditions related with inventory level. In addition, while transporting and keeping items, it has more probability to be exposed to various risk factors.

In this paper, we propose for the TPL service provider to determine the optimal order quantity considering defective items under the VMI and JIT conditions. By developing the mathematical model for the total cost for the TPL service provider based on the transactions with vendors and manufacturer, we can derive the optimal order quantity for TPL and determine the basic conditions to guarantee the existence of an optimal solution. In addition, we have examined the impact on the total cost and optimal order quantity from parameters such as the random variables of the expected defective rate of the incoming lot from vendors, and the actual defective rate. The results of the sensitive analysis demonstrate that the proposed model can reduce the order quantity and corresponding cost related to the inventory, while maintaining the total cost at a minimum.

However, there exist some limitations related to the proposed model and its application to a practical business environment. We assume an infinite production capacity for the vendor and that the demand from the manufacturer is deterministic. In addition, our model also assumes that the cause of the defective items can be clearly determined and agreed between the vendor and TPL. By compensating for these limitations, it may be possible to create a balance between the vendor, TPL and manufacturer, and maximize the benefit of the VMI and JIT strategies.

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