

# Cooperative Vendor-Buyer Inventory Model with Imperfect Quality and Inspection Errors

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**Abstract**—This paper develops an integrated inventory model consisting of single-vendor and single-buyer system. The demand in buyer side is deterministic and the production process is imperfect and produces a certain number of defective items. The delivery within a single production batch from vendor to buyer is increasing by a fixed factor. After the delivery arrives at the buyer, an inspection process is conducted. The inspection process is not perfect. Errors may occur when the inspector misclassifies a non-defective item as defective or incorrectly classifies a defective item as non-defective. This model provides an optimal solution for the expected integrated total annual cost of the vendor and the buyer. The result from numerical examples shows that the integrated model will result in lower joint total cost in comparison with the equal-sized policy.

**Keywords**—Integrated inventory model, Vendor-buyer system, Unequal size, Imperfect quality, Inspection errors

## I. INTRODUCTION

WITH the growing business in nowadays, firms have been attempting to achieve greater performance in their supply chain. Since improving supply chain was considered to be the key factor in managing modern business, many firms realized that the best strategies in managing inventories across the supply chain can be more efficiently achieved through better cooperation and better integration with their supply chain partners.

The integrated inventory management model in the supply chain has received a great deal of attention since more than three decades ago. Since Goyal [1] introduced the integrated inventory model consisting of a vendor and a buyer, many researchers have developed the models under various cases, such as [2], [3], [4], [5], [6], [7], [8], [9].

Further, Goyal [10] developed a model of vendor-buyer with unequal-sized shipment. Some researchers, including [11], [12], [13], [14], [15] proposed vendor-buyer model under unequal-sized shipment and proved that the proposed policy gives an impressive cost reduction in comparison to equal-sized policy. The above mentioned papers assumed that the product produced by the vendor is always in perfect

quality. However, in real situation, the production process may produce a certain number of defective items. Porteus [16] was among the first researchers who introduced an EPQ model considering defective items and showed a significant relationship between quality and lot size.

Therefore, some researchers are interested in developing inventory model considering imperfect quality. Salameh and Jaber [17] developed an EOQ model assuming that the lot contains a random proportion of defective items. The model assumed that there is no error caused by human in the inspection process. Then, Raouf et al. [18] studied human errors in inspection. Yoo et al. [19] proposed a model that considered both imperfect production and two-way imperfect inspection. The model considered the situation in which the inspector may incorrectly classify a non-defective item as defective (Type I inspection error), or incorrectly classify a defective item as non-defective (Type II inspection error). Lin [20] developed a model for simple supply chain system based on [19] and assumed that both Type I and Type II inspection errors are known constants. Hsu and Hsu [21] then developed an integrated vendor-buyer inventory model for items with imperfect quality and inspection errors. This model assumes that the defective items are sold to a secondary market at a discounted price. Furthermore, Darwish et al. [22] examined the effect of imperfect quality in vendor-buyer system under vendor managed inventory model.

Most of above models, studied vendor-buyer model with defective items and equal-sized shipment. Pamudji et al. [23] developed a model with unequal-sized shipment policy and defective items and also showed that the proposed model can reduce the total cost significantly compared to equal-sized shipment. In this paper, we propose an integrated inventory model for single-vendor single-buyer which considers unequal-sized shipment, defective items, and inspection errors for vendor-buyer system.

## II. ASSUMPTIONS AND NOTATIONS

### 2.1 Assumptions

The assumptions used in this paper are:

- 1) The demand rate is known, constant, and continuous.
- 2) The lead time is zero.
- 3) Demand is deterministic.
- 4) Backorder and shortage are not allowed.
- 5) Production rate is greater than the demand rate.
- 6) Product lots which are sent from the vendor to the buyer contain defective items with defect rate of  $\gamma$ .
- 7) The inspection process is imperfect and the probability of classifying a non-defective as defective is  $e_1$ .
- 8) The probability of classifying a defective as non-

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defective is  $e_2$ .

- 9) The buyer returns all items classified as defective.
- 10) The items those returned from the customer to the vendor at the end of the 100% screening process will be given a full price refund from the vendor.
- 11) The vendor incurs a cost of  $c_w$  for each defective item.
- 12) The vendor will sell the returned items at a discounted price to a secondary market. Therefore,  $c_r$  is the difference between the regular and the discounted price.
- 13) Customer who buys the defective items will detect the quality problem and return them to the buyer and received a good item for replace. Both the vendor and the buyer incur a post-sale failure cost for the items returned from the market.

### 2.2 Notations

- $D$  : Demand rate
- $P$  : Production rate
- $Q$  : The first shipment size of each batch in early production lot
- $F$  : Transportation cost per shipment (including the shipment of  $Q$  units from the vendor to the buyer and the returned items from the buyer to the vendor)
- $S_b$  : Ordering cost per order for the buyer
- $S_v$  : Setup cost per production run for the vendor
- $n$  : The number of shipments per batch production run, a positive integer
- $\lambda$  : The increasing rate of delivery lot size
- $\gamma$  : The probability that an item produced is defective
- $x$  : Inspection rate
- $c_i$  : Inspection cost per unit for buyer
- $c_w$  : Unit cost for producing defective items for vendor
- $c_{ab}$  : Post-sale defective items cost for buyer

- $c_{av}$  : Post-sale defective items cost for vendor
- $c_r$  : The cost of rejecting a non-defective item
- $H_v$  : The holding cost per unit per year for the vendor
- $H_b$  : The holding cost per unit per year for the buyer
- $JTC$  : Joint total cost
- $B_1$  : The number of items that are classified as defective in each delivery of  $Q$  units
- $B_2$  : The number of items that are returned from the market in each delivery of  $Q$  units
- $e_1$  : The probability of a Type I inspection error (classifying a non-defective item as defective)
- $e_2$  : The probability of a Type II inspection error (classifying a defective item as non-defective)

### III. MODEL DEVELOPMENT

Here, we discuss about a single item in a single-vendor single-buyer inventory problem with unequal-sized shipment, defective items, and inspection errors. The terminology for the proposed unequal-sized policy is adopted from [23] and the production rate is greater than the demand rate ( $P > D$ ). We assume that the production rate is greater than the demand rate ( $P > D$ ). The first shipment is conducted with a lot size of  $Q$ . Then, the next shipments are done with a lot size of  $\lambda^{n-1}Q$ .  $\lambda$  is the growth factor which is determined between 1 and  $P/D$ . Each lot contains a probability of defective items  $\gamma$  and after receiving the lot from the vendor, the buyer performs the inspection process. The inspection process is not perfect. While inspecting the items, errors may occur because of human activity. The inspector may misclassify non-defective items as defective with probability  $e_1$ , or misclassify defective items as non-defective. The defective item which are found by inspector in buyer's inspection process and each defective item that returned from the market to the vendor as a single batch at

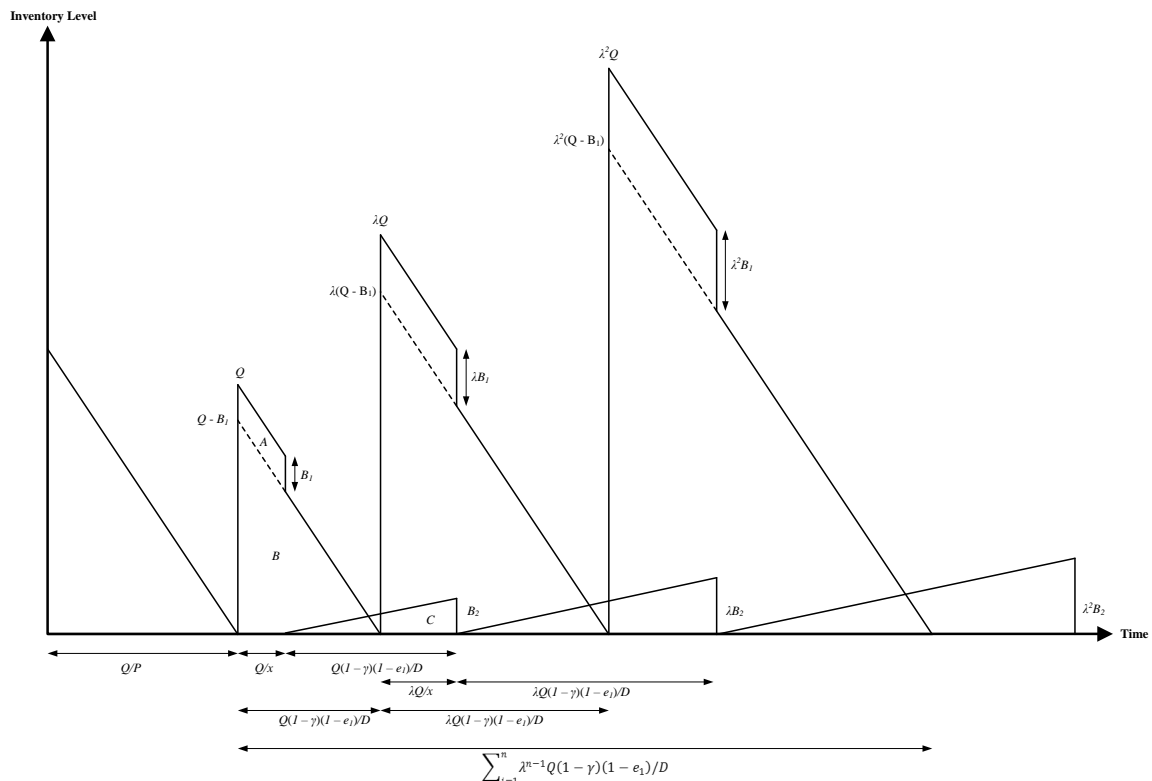


Fig. 1. Buyer's inventory level

the end of the inspection process will receive a full price refund from the vendor as a warranty. The vendor will incur a cost  $c_w$  from each defective item and incurs a cost of  $c_r$  for each non-defective items classified as defective. The vendor will incur a cost  $c_w$  from each defective item and incur a cost of  $c_r$  for each non-defective item classified as defective. The buyer incurs a post-sale cost  $c_{ab}$  per unit item returned from the market while the vendor incurs  $c_{av}$  per unit item.

The objective function of this model is to minimize the joint total cost per unit time ( $TC$ ) that consists of the buyer's total inventory cost ( $TC_B$ ) and the vendor's total inventory cost ( $TC_V$ )

### 3.1 The Buyer's Cost Formulation

The buyer's total inventory cost consists of ordering cost ( $OC_b$ ), delivery cost ( $FC$ ), inspection cost ( $IC$ ), post-sale failure cost ( $PC$ ), and the buyer's holding cost ( $HC_b$ ).

Fig. 1 shows the buyer's inventory level for each ordering cycle. By definition,  $B_1$  is calculated as follows

$$B_1 = Q(1 - \gamma)e_1 + Q\gamma(1 - e_2) \quad (1)$$

$$B_2 = Q\gamma e_2 \quad (2)$$

The production batch can be calculated as follows

$$\sum_{i=1}^n \lambda^{i-1} (Q - B_1 - B_2) = \frac{Q(1-\gamma)(1-e_1)(\lambda^n-1)}{(\lambda-1)} \quad (3)$$

Hence, a number of production cycle can be formulated by dividing the demand ( $D$ ) with (3):

$$\frac{D}{Q(1-\gamma)(1-e_1)(\lambda^n-1)/(\lambda-1)} \quad (4)$$

The total defective items per production cycle can be formulated by considering the rectangle A in Fig. 1, that is

$$HC_{b1} = \frac{Q^2(\lambda^{2n}-1)(1-\gamma)e_1}{x(\lambda^2-1)} + \frac{Q^2\gamma(\lambda^{2n}-1)(1-e_2)}{x(\lambda^2-1)} \quad (5)$$

Meanwhile, the total inventory for buyer per production run can be calculated by considering the triangle B in Fig. 1 and is formulated by

$$HC_{b2} = \frac{(\lambda^{2n}-1)}{(\lambda^2-1)} \cdot \frac{Q^2[1-(1-\gamma)e_1+\gamma(1-e_2)](1-\gamma)(1-e_1)}{2D} \quad (6)$$

Thus, by considering the triangle C in Fig. 1, the total item items returned from the market in one production cycle is given as follows

$$HC_{b3} = \frac{(\lambda^{2n}-1)}{(\lambda^2-1)} \cdot \frac{Q^2\gamma e_2(1-\gamma)(1-e_1)}{2D} \quad (7)$$

Further, the holding cost for the buyer in one production cycle can be found by adding (5) and (6) into (7), that is

$$HC_b = H_b Q D \left\{ \frac{(\lambda^{2n}e_1 - \lambda^{2n}\gamma e_1 - e_1 + \gamma e_1) + (\lambda^{2n}\gamma - \lambda^{2n}\gamma e_2 - \gamma + \gamma e_2)}{x(\lambda+1)(1-\gamma)(1-e_1)(\lambda^n-1)} \right\} + \frac{H_b Q \gamma e_2 (\lambda^n+1)}{2(\lambda+1)} + \frac{H_b Q e_1 (1-e_1 + \gamma e_1 + \gamma - \gamma e_2) (\lambda^n+1)}{(\lambda+1)} \quad (8)$$

After adding the warranty, ordering, delivery, inspection, and post-sale failure cost for each production run, the buyer's total cost is given by

$$ETC_b(n, Q, \lambda) = (S_b + nF) \frac{D(\lambda-1)}{Q(1-\gamma)(1-e_1)(\lambda^n-1)} + (c_i + c_{ab}\gamma e_2) \frac{D}{(1-\gamma)(1-e_1)} + H_b Q D \left\{ \frac{(\lambda^{2n}e_1 - \lambda^{2n}\gamma e_1 - e_1 + \gamma e_1) + (\lambda^{2n}\gamma - \lambda^{2n}\gamma e_2 - \gamma + \gamma e_2)}{x(\lambda+1)(1-\gamma)(1-e_1)(\lambda^n-1)} \right\} + \frac{H_b Q \gamma e_2 (\lambda^n+1)}{2(\lambda+1)} + \frac{H_b Q e_1 (1-e_1 + \gamma e_1 + \gamma - \gamma e_2) (\lambda^n+1)}{(\lambda+1)} \quad (9)$$

### 3.2 The Vendor's Cost Formulation

The vendor's total inventory cost consist of setup cost, warranty cost, Type I and Type II errors cost, and holding cost for the vendor. The holding cost for vendor is based on

[23], that is

$$BS_v = H_v \left\{ \frac{DQ}{P} + \frac{(P-D)Q(\lambda^n-1)}{2P(\lambda-1)} - \frac{Q(\lambda^n+1)}{2(\lambda+1)} (1-\gamma)^2 - \frac{Q\gamma D(\lambda^n+1)}{x(\lambda+1)} \right\} \quad (10)$$

The total cost for the vendor can be formulated by adding the setup cost, warranty cost, Type I and Type II errors costs into (10). The formulation is as follows

$$ETC_v(n, Q, \lambda) = S_v \frac{D(\lambda-1)}{Q(1-\gamma)(1-e_1)(\lambda^n-1)} + (c_w\gamma + c_{av}\gamma e_2) \frac{D}{(1-\gamma)(1-e_1)} + \frac{c_r D e_1}{(1-e_1)} + H_v \left\{ \frac{DQ}{P} + \frac{(P-D)Q(\lambda^n-1)}{2P(\lambda-1)} - \frac{Q(\lambda^n+1)}{2(\lambda+1)} (1-\gamma)^2 - \frac{Q\gamma D(\lambda^n+1)}{x(\lambda+1)} \right\} \quad (11)$$

### 3.3 Joint Total Cost Formulation

The joint total cost for vendor-buyer is formulated by summing the buyer cost (9) and the vendor cost (11). The formulation is given as follows

$$JTC(n, Q, \lambda) = \frac{(S_b + S_b + nF)D(\lambda-1)}{Q(1-\gamma)(1-e_1)(\lambda^n-1)} + \frac{(c_w\gamma + c_i + c_{ab}\gamma e_2 + c_{av}\gamma e_2)D}{(1-\gamma)(1-e_1)} + \frac{c_r D e_1}{(1-e_1)} + H_b Q D \left\{ \frac{(\lambda^{2n}e_1 - \lambda^{2n}\gamma e_1 - e_1 + \gamma e_1) + (\lambda^{2n}\gamma - \lambda^{2n}\gamma e_2 - \gamma + \gamma e_2)}{x(\lambda+1)(1-\gamma)(1-e_1)(\lambda^n-1)} \right\} + \frac{H_b Q \gamma e_2 (\lambda^n+1)}{2(\lambda+1)} + \frac{H_b Q e_1 (1-e_1 + \gamma e_1 + \gamma - \gamma e_2) (\lambda^n+1)}{(\lambda+1)} \quad (13)$$

### 3.4 Solution Methodology

In this section, we develop a solution methodology to find the optimal solution of the model. Taking the first partial derivative of  $ETC(n, Q, \lambda)$  with respect to  $Q$ , we obtain

$$\frac{\partial JTC(n, Q, \lambda)}{\partial Q} = - \frac{(S_b D + S_b D + nFD)(\lambda-1)}{Q^2(1-\gamma)(1-e_1)(\lambda^n-1)} + \frac{H_b D}{P} + \frac{H_v(P-D)(\lambda^n-1)}{2P(\lambda-1)} - \frac{H_v(\lambda^n+1)(1-\gamma)^2}{2(\lambda+1)} + H_b D \left\{ \frac{(\lambda^{2n}e_1 - \lambda^{2n}\gamma e_1 - e_1 + \gamma e_1) + (\lambda^{2n}\gamma - \lambda^{2n}\gamma e_2 - \gamma + \gamma e_2)}{x(\lambda+1)(1-\gamma)(1-e_1)(\lambda^n-1)} \right\} - \frac{H_b \gamma D (\lambda^n+1)}{x(\lambda+1)} + \frac{H_b \gamma e_2 (\lambda^n+1)}{2(\lambda+1)} + \frac{H_b e_1 (1-e_1 + \gamma e_1 + \gamma - \gamma e_2) (\lambda^n+1)}{(\lambda+1)} \quad (14)$$

Taking the second derivative of  $ETC(n, Q, \lambda)$  with respect to  $Q$  we will find

$$\frac{\partial^2 JTC(n, Q, \lambda)}{\partial Q^2} = \frac{2(S_b D + S_b D + nFD)(\lambda-1)}{Q^3(1-\gamma)(1-e_1)(\lambda^n-1)} \quad (15)$$

Clearly, it can be seen in (15) that  $\frac{\partial^2 JTC(n, Q, \lambda)}{\partial Q^2} > 0$  with fixed value of  $n$  and  $\lambda$ . It implies that the joint total cost for vendor-buyer is a convex function, hence there is exist the optimal value of shipment quantity that minimizes (13). By setting (14) equals to zero, the optimal shipment quantity is given by

$$Q^* = \sqrt{\frac{(S_b D + S_b D + nFD)(\lambda-1)}{(1-\gamma)(1-e_1)(\lambda^n-1)}} \frac{1}{Y+Z} \quad (16)$$

with

$$Y = \frac{H_b D}{P} + \frac{H_v(P-D)(\lambda^n-1)}{2P(\lambda-1)} - \frac{H_v(\lambda^n+1)(1-\gamma)^2}{2(\lambda+1)} - \frac{H_b \gamma D (\lambda^n+1)}{x(\lambda+1)}$$

and

$$Z = H_b D \left\{ \frac{(\lambda^{2n}e_1 - \lambda^{2n}\gamma e_1 - e_1 + \gamma e_1) + (\lambda^{2n}\gamma - \lambda^{2n}\gamma e_2 - \gamma + \gamma e_2)}{x(\lambda+1)(1-\gamma)(1-e_1)(\lambda^n-1)} \right\} + \frac{H_b \gamma e_2 (\lambda^n+1)}{2(\lambda+1)} + \frac{H_b e_1 (1-e_1 + \gamma e_1 + \gamma - \gamma e_2) (\lambda^n+1)}{(\lambda+1)}$$

IV. NUMERICAL EXAMPLES

In this paper, we consider an example given by Hsu and Hsu [21], where:

- $P = 160.000$  units/year
- $D = 50.000$  units/year
- $x = 175.200$  units/year
- $S_v = \$300$ /production run
- $S_b = \$100$ /order
- $H_v = \$2$ /unit/year
- $H_b = \$5$ /unit/year
- $F = \$25$ /delivery
- $c_i = \$0,5$ /unit
- $c_w = \$50$ /unit
- $c_r = \$100$ /unit
- $c_{ab} = \$200$ /unit
- $c_{av} = \$300$ /unit

If the defective percentage and inspections errors follow a uniform with

$$f(\gamma) = \begin{cases} \frac{1}{\beta}, & 0 \leq \gamma \leq \beta \\ 0, & \text{otherwise} \end{cases}$$

$$f(e_1) = \begin{cases} \frac{1}{\lambda}, & 0 \leq e_1 \leq \lambda \\ 0, & \text{otherwise} \end{cases}$$

$$f(e_2) = \begin{cases} \frac{1}{\eta}, & 0 \leq e_2 \leq \eta \\ 0, & \text{otherwise} \end{cases}$$

Then we have

$$E[\gamma] = \int_0^\beta \gamma f(\gamma) d\gamma = \int_0^\beta \frac{\gamma}{\beta} d\gamma = \frac{\beta}{2},$$

$$E[\gamma^2] = \int_0^\beta \gamma^2 f(\gamma) d\gamma = \int_0^\beta \frac{\gamma^2}{\beta} d\gamma = \frac{\beta^2}{3},$$

$E[e_1] = \frac{\lambda}{2}$ ,  $E[e_1^2] = \frac{\lambda^2}{3}$ , and  $[e_2] = \frac{\eta}{2}$ . Specifically, if  $\beta = \lambda = \eta = 0,04$ , the impact of of defective rate on proposed model can be seen in table 1.

TABLE I  
THE IMPACT OF DEFECTIVE RATE ON MODEL

Parameters	$\gamma$					
	0,02	0,03	0,04	0,05	0,06	0,07
$n$	3	3	3	3	3	3
$\lambda$	3,2	3,2	3,2	3,2	3,2	3,2
$Q$	729,75	707,99	688,44	670,76	654,70	640,02
<b>Buyer Cost</b>						
Ordering Cost	\$494,06	\$514,49	\$534,62	\$554,48	\$574,13	\$593,61
Delivery Cost	\$370,54	\$385,87	\$400,96	\$415,86	\$430,60	\$445,21
Inspection Cost	\$26.030,82	\$26.299,18	\$26.573,13	\$26.852,85	\$27.138,51	\$27.430,33
Post-sales Failure Cost	\$4.164,93	\$6.311,80	\$8.503,40	\$10.741,14	\$13.026,49	\$15.360,98
Holding Cost	\$364,73	\$442,29	\$517,79	\$591,71	\$664,41	\$736,22
<b>Total Buyer Cost</b>	<b>\$31.425,09</b>	<b>\$33.953,63</b>	<b>\$36.529,90</b>	<b>\$39.156,03</b>	<b>\$41.834,14</b>	<b>\$44.566,34</b>
<b>Vendor Cost</b>						
Setup Cost	\$1.482,18	\$1.543,48	\$1.603,85	\$1.663,43	\$1.722,38	\$1.780,82
Warranty Cost	\$52.061,64	\$78.897,54	\$106.292,52	\$134.264,23	\$162.831,09	\$192.012,29
Type I Error Cost	\$102.040,82	\$102.040,82	\$102.040,82	\$102.040,82	\$102.040,82	\$102.040,82
Type II Error Cost	\$6.247,40	\$9.467,70	\$12.755,10	\$16.111,71	\$19.539,73	\$23.041,47
Holding Cost	\$2.032,34	\$2.066,49	\$2.100,46	\$2.134,15	\$2.167,49	\$2.200,45
<b>Total Vendor Cost</b>	<b>\$163.864,37</b>	<b>\$194.016,03</b>	<b>\$224.792,74</b>	<b>\$256.214,34</b>	<b>\$288.301,52</b>	<b>\$321.075,85</b>
<b>Joint Total Cost</b>	<b>\$195.201,03</b>	<b>\$227.969,66</b>	<b>\$261.322,64</b>	<b>\$295.370,37</b>	<b>\$330.135,65</b>	<b>\$365.642,19</b>

The optimal solution from Hsu and Hsu [21] policy is to manufacture in batches ( $Q^*$ ) of 791 units with  $n = 7$ , and the minimum total cost is \$201.358,50. Using our proposed model, the optimal solutions from the above problem are  $Q^* = 1.101,39$ ,  $n = 3$  with the shipments sizes 2.335,19 units, 4.670,38 units, and 7.005,57 units. For the minimum total cost in the proposed model is \$195.201,03.

Table I gives the illustration of the effect of the changes in defective rate on proposed model. From Table I, it can be seen that the increasing of defective rate will affect the total buyer cost, total vendor cost, and joint total cost. For the vendor, the increasing number of defective items gives significant impact to post-sales failure cost.

V. CONCLUSION

In this paper, we develop a single-vendor single-buyer inventory model for single product considering unequal-sized shipment under deterministic demand, imperfect quality, and inspection errors. The joint total cost of the vendor and buyer is derived and a solution procedure is provided to find the optimal solution that can minimize the joint total cost. The result from numerical example shows that the model can give benefit to both parties. In addition, the joint total cost decreases when the defect rate decreases.

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