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Research Article

Optimization of Joint Economic Lot Size Model for Vendor-Buyer with Exponential Quality Degradation and Transportation by Chimp Optimization Algorithm

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Freight transportation plays a critical role in improving company performance in the modern manufacturing industry. To reduce costs, companies must take advantage of the use of large vehicles. It caused fewer deliveries, but inventory costs and degradation quality are high. One of the joint economic lot size (JELS) problems in supply chain is Integrated Single-Vendor Single-Buyer Inventory Problem (I-SVSB-IP). This study developed the I-SVSB-IP model that considers raw materials' exponential quality degradation and transportation costs. The objective function of this research was to maximize the Joint Total Profit (JTP). Three decision variables used were inventory cycle time *(T)*, raw material ordering frequency (*m*), and frequency of delivery of finished products to buyers *(n)*. This study proposed a sophisticated Chimp Optimization Algorithm (ChOA) procedure to solve the I-SVSB-IP problem. A case study on the food industry in Indonesia was presented to optimize the I-SVSB-IP. The results showed that the ChOA procedure had produced an optimal solution compared to the state-of-the-art algorithm. This study also demonstrated a sensitivity analysis of decision and transportation variables to cost, revenue, and JTP. The results show that increasing transport frequency of ordering raw materials (m) and finished products to buyers (n) enhances the total cost and reduces joint total profit. In addition, increasing the rate of quality degradation of raw materials reduces JTP.

1. Introduction

Currently, company performance is influenced by the effectiveness of supply chain management (SCM) [1–3]. SCM plays an essential role in integrating various company parts to increase competitive advantage [4, 5]. SCM is an approach used to incorporate decisions from upstream to downstream to minimize costs in the system [6]. Several efforts are made to improve company performance, such as advanced continuous replenishment, continuous partnerships, quick response, and integrated inventory decision [7, 8]. Integrated inventory is proven to have the best performance in many companies [9, 10]. The freight transportation problem has a vital role in improving company performance [11]. In general, research on fuel reduction in freight transportation is interesting to investigate. One way to reduce fuel consumption is to minimize delivery frequency [12, 13]. Companies need to take advantage of the use of large vehicles to increase vehicle utilization to reduce costs. This decision impacts the low frequency of delivery. However, the inventory costs incurred are high, causing high operating costs for the company [14–16]. In addition to transportation problems, the problem of decreasing quality is an important problem in inventory [17]. The decrease in the quality of raw materials impacts the quality of the finished product, which is not in accordance with company standards [18]. In addition, it also has an impact on high operational costs in the company. Excess raw material inventory causes degradation of raw material quality. Park [19] was the first researcher to develop an integrated production-inventory model for decaying raw materials. Unfortunately, this research assumes non-perishable raw materials. Many perishable products experience an exponential decline in quality.

Joint economic lot size (JELS) problems are commonly used in the inventory literature to describe the problem of making joint lot sizing decisions involving multiple entities in a supply chain [20]. One of the JELS problems is integrating inventory management decisions at the vendor and buyer levels [21, 22]. This problem is called the Integrated Single-Vendor Single-Buyer Inventory Problem (I-SVSB-IP) [23]. This problem has received wide attention from researchers [24, 25]. One of the products that have unique characteristics is food product. Food products can degrade in both exponential and linear ways [26, 27]. Generally, some research studies assume that the degradation quality of raw materials is linear. However, in fact, some products have characteristics of exponential quality degradation. Furthermore, transportation costs in procurement and deliveries activities are rarely considered in the investigation. These costs influence total cost and profit, so transportation costs need to be studied in increasing company profits. In addition, in previous studies, research generally assumes that the demand for finished products is the same as the need for raw materials. However, for some products, the demand for raw materials is not the same as the demand for finished products.

Based on previous research, the I-SVSB-IP study that discussed exponential quality degradation and transportation costs for food products was not investigated. The proposed transportation cost model considers the transportation of raw material delivery and finished product delivery. This reason was the first motivation for this research. Some products with an exponential decrease in quality are categorized as perishable products [28, 29]. Some of the products that suit these characteristics are food products [30], pharmaceuticals [31], and agricultural products [32]. In addition, several metaheuristic procedures have been offered for inventory optimization. Some of these algorithms include Genetic Algorithm (GA) [33–36], Particle Swarm Optimization (PSO) [37], PSO and GA [9], simulated annealing [38], Harmony Search (HS) [39], and Evolutionary Algorithm [40, 41]. Of the several proposed algorithms, the popular metaheuristic algorithms used to optimize the vendor-buyer inventory model problem are GA [33–36], PSO [37], and PSO and GA [9]. Unfortunately, no studies utilized the Chimp Optimization Algorithm (ChOA) to solve the I-SVSB-IP. The ChOA is a new sophisticated metaheuristic procedure that has been inspired by chimp behavior in food hunting [42]. In 2020, this algorithm was proposed by Khishe and Mosavi [42] to solve continuous problems. The ChOA has also been successfully applied for classification [43] and digital filters [44]. This reason is what motivates researchers to use a ChOA as an optimization tool for I-SVSB-IPs.

The following two questions are addressed in this study, based on the findings of the previous gap analysis:

(1) How do transportation activities and exponential quality degradation affect the time/length during the inventory cycle and the total profit of the integrated Inventory system in the I-SVSB-IP?

(2) How to use and perform ChOA as an optimization tool for I-SVSB-IPs?

Therefore, this study offers the I-SVSB-IP model by involving exponential quality degradation and transportation costs. This study develops an exponential quality degradation raw material model from the research conducted by Fauza et al. [34]. As described above, their research considers linear quality degradation. The transportation costs considered in the I-SVSB-IP were the transportation costs for the procurement of raw materials and delivery of finished products. This study develops the transportation cost model proposed by Bonney and Jaber [45]. The decision variables of this study are inventory cycle time (T), frequency of raw material ordering (m), and frequency of delivery of finished products (n). This study also considers the model that is converted from demand for finished products to raw materials. In addition, this study proposed the ChOA as an optimization tool to solve the I-SVSB-IP. Therefore, the contributions of this study are as follows. (1) It offers a new I-SVSB-IP model involving exponential quality degradation and transportation costs. (2) It proposes the ChOA as an optimization tool to solve problems.

The structure of this paper is presented as follows. Section 2 describes the literature review, and the characteristics of the system are presented in Section 3. Next, assumptions and notations are described in Section 4. Then, the mathematical model of the I-SVSB-IP system is discussed in Section 5, while the proposed algorithm for I-SVSB-IP is presented in Section 6. Next, Section 7 discusses data collection and experimental procedures, while the results and discussion are discussed in Section 8. Finally, the conclusion and suggestions are given in Section 9.

2. Literature Review

In this section, this article discusses the literature review in the field of I-SVSB-IPs. Researchers have published several I-SVSB-IP studies. Banerjee [46] is the first researcher to examine the I-SVSB-IP problem with one decision variable: lot size. In his research, the vendor had a role as a manufacturer. Furthermore, Goyal [47], Goyal and Gupta [48], Hill [49], and Lu [50] investigated a similar issue. Moreover, this model was developed by Hill and Omar [51] to determine the production and shipment policy. Ben-Daya and Raouf [52] developed a model taking the lead time into account. This model was developed by Ouyang et al. [53], involving backorders and lost sales. A model that considers continuous replenishment and just-in-time purchasing was proposed by Yao et al. [54]. A model involving multiple production setups and rework was proposed by Sekar and Uthayakumar [55]. In addition, a model that considered the lead times and stochastic demand was introduced by Mou et al. [56]. Meanwhile, AlDurgam et al. [57] developed a model with stochastic demand and variable production rates. A model considering the transport-inventory system was constructed by Zanoni and Zavanella [58].

Several studies on the I-SVSB-IP model with imperfect quality were also proposed. Lee and Kim [59] projected the I-SVSB-IP model by considering deteriorating and defective items. Liu et al. [60] suggested the I-SVSB-IP model with declining production and shipment policy items. A model considering learning effect, fuzzy demand, and imperfect quality were also proposed by Fu et al. [61]. Based on previous studies, research that discusses quality degradation is scarce. Only four papers were recorded discussing deteriorating and defective items as presented by Liu et al. [60], Fu et al. [61], Fauza et al. [34], and Lee and Kim [59]. A food product is one of the products that have unique characteristics. There are both linear and exponential degradation aspects of food products [26, 27]. Unfortunately, to our knowledge, only Fauza et al. [34] discussed the I-SVSB-IP model for food products. Their study assumes that raw material degradation quality is linear.

In addition, several studies included integrated vendor-buyer research involving transportation costs. Zanoni and Zavanella [58], Wangsa and Wee [62], and Wangsa et al. [63] have considered transportation costs in these studies. Transportation costs were considered in two recent studies by Wangsa and Wee [62] and Wangsa et al. [63]. However, neither of them considered the possibility of quality degrading at an exponential rate. Researchers in this field examined how products get from the manufacturer to the customer. Unfortunately, transportation costs for raw materials are not taken into account in the model they have created. The model with stochastic demand, defective items, and carbon emission cost was modeled by Jauhari [64]. The model with reliability, carbon emission, and inspection errors in a defective production system was developed by Sangal et al. [65]. Jauhari [66] formulated ith defective items, inspection error, and stochastic demand. Recently, Çömez-Dolgan et al. [67] proposed the I-SVSB-IP model, which involves untimely delivery. The model by considering the bounded production cycle length was offered by Herbon [68].

The comparison of this study with previous studies in I-SVSB-IP is presented in Table 1. It shows that the objective function of minimizing cost dominates the I-SVSB-IP problem. On the other hand, the objective function of profit maximization is still rarely investigated. In this study, transportation costs for procurement activities and delivery activities are considered. In addition, this research involves a decrease in the quality of raw materials and shelf-life-based price function for finished products at the buyer level. The ChOA is proposed as a sophisticated procedure to optimize this problem.

3. System Characteristics

The characteristics of the I-SVSB-IP are illustrated in Figure 1. This figure displays that the raw material is purchased by a vendor (manufacturer). Vendors order raw material m times to fulfill production demand with the amount of D during the production cycle of T. Vendors use the mode of transportation to purchase raw material for m times to the supplier. The total raw material required in production is λ. D. λ is the conversion coefficient from finished goods to raw material. In raw material storage at vendors (manufacturers), raw materials decrease quality. Furthermore, raw materials are processed into finished products with a production level of P. The finished product is then sent to the buyer as many as n times to fulfill the D end customer's demand. Vendors use the mode of transportation to deliver finished products for n times to buyers. At the storage of raw materials at the buyer level, the finished product decreases quality. The finished product also has an expiration date. As the expiration date approaches, the product has a cheaper selling price [29].

Figure 2 shows an inventory system on the I-SVSB-IP. Two types of materials studied in the I-SVSB-IP are raw materials and finished products. Vendors (manufacturers) procure raw materials from suppliers. The procurement quantity of raw materials for each shipment is qr. The raw material procurement cycle can be formulated as $qr/\lambda\ D$. Furthermore, the raw material needed to fulfill the demand for finished products (D) is λD, where λ is the conversion coefficient of the conversion of raw materials to finished products. The company carries out production at a production rate of P. Therefore, the rate of raw material for production is λP. During one inventory cycle, products are produced during the Tp period to fulfill buyer D. The number of finished products to meet the demand during the production cycle T is denoted as $Qp = \mathrm{DT}$. Tp can be calculated with the DT/P formula. Furthermore, the finished product is shipped for n times the number of batches of qp size. Therefore, the cycle of ordering the finished product by the buyer can be calculated by qp/D.

4. Assumptions and Notations

This study uses assumptions based on the research of Fauza et al. [34] and Fauza et al. [29]. The assumptions used in the I-SVSB-IP are as follows: (1) raw material quality decreases exponentially during storage, (2) shortage and backorder are not allowed, (3) production rates and demand levels are constant, (4) load does not significantly affect fuel consumption, (5) production rate > demand rate, (6) delivery lead time is ignored, (7) the capacity of the vehicle is neglected, and (8) the rate of exponential degradation raw material for one cycle is 0 to 1. The notations used in this model include the following:

P: production rate for producing the finished product (units/month).

D: number of demands for finished products (units/month).

λ: conversion coefficient of the finished product to raw material.

q_r: the size of the raw material order (unit).

q_p: finished product delivery size (unit).

k: rate of quality degradation of raw materials (quality units/month).

$Q_{\max}$: maximum quality of raw material (quality units).

$Q_{\min}$: minimum quality of raw materials (quality units).

$Q(t)$: remaining quality at time t for raw material (quality units).

Table 1: Comparison of this study with previous studies in I-SVSB-IP.

Author	Transportation cost		Quality degradation/ deterioration	Shelf-life-based price function	Objective function		Solution procedure
	Procurement activities	Delivery activities			Minimize total cost	Maximize profit	
	—	—	—	—	V	—	Exact
Goyal [47]	—	—	—	—	V	—	Exact
Goyal and Gupta [48]	—	—	—	—	V	—	Exact
Hill [49]	—	—	—	—	V	—	Heuristic
Lu [50]	—	—	—	—	V	—	Heuristic
Hill and Omar [51]	—	—	—	—	V	—	Heuristic
Ben-Daya and Raouf [52]	—	—	—	—	V	—	Heuristic
Ouyang et al. [53]	—	—	—	—	V	—	Heuristic
Yao et al. [54]	—	—	—	—	V	—	Heuristic
Sekar and Uthayakumar [55]	—	—	V	—	V	—	GA
Mou et al. [56]	—	—	—	—	V	—	Heuristic
AlDurgam et al. [57]	—	—	—	—	V	—	Heuristic
Banerjee [46], Liu et al. [60]	—	—	V	—	V	—	Heuristic
Fu et al. [61]	—	—	V	—	V	—	Heuristic
Fauza et al. [34]	—	—	V	V	-	V	GA
Lee and Kim [59]	—	—	V	—	—	V	Heuristic
Zanoni and Zavanella [58]	—	V	—	—	V	—	Heuristic
Wangsa and Wee [62]	—	V	—	—	V	—	Heuristic
Wangsa et al. [63]	—	V	—	—	V	—	Heuristic
Çömez-Dolgan et al. [67]	—	—	—	—	V	—	Heuristic
Herbon [68]	—	V	—	—	V	—	Heuristic
Jauhari [64]	—	V	—	—	V	—	Heuristic
Jauhari [66]	—	—	—	—	V	—	Heuristic
This research	V	V	V	V	—	V	ChOA

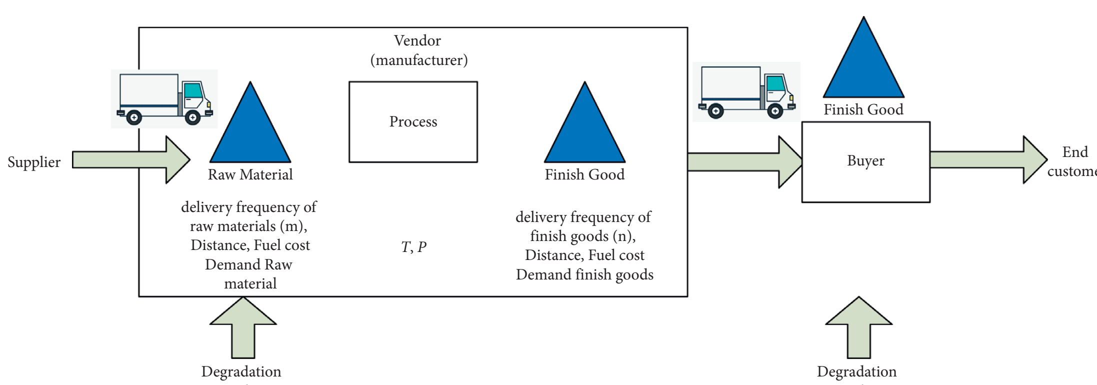

Figure 1: Characteristics of the I-SVSB-IP.

c_{loss}: costs due to quality degradation of raw materials (rupiahs/quality units/month).

c_{sale}: costs of purchasing finished products from buyers to vendors (rupiahs/order).

c_{r}: the cost of purchasing raw materials (IDR/order).

c_{p}: costs for processing the finished product (IDR/unit).

A_r: transportation costs for the procurement of materials (IDR/order).

A_p: transportation costs for the delivery of the finished product (IDR/delivery).

a_r: fixed costs of raw material transportation (IDR/order).

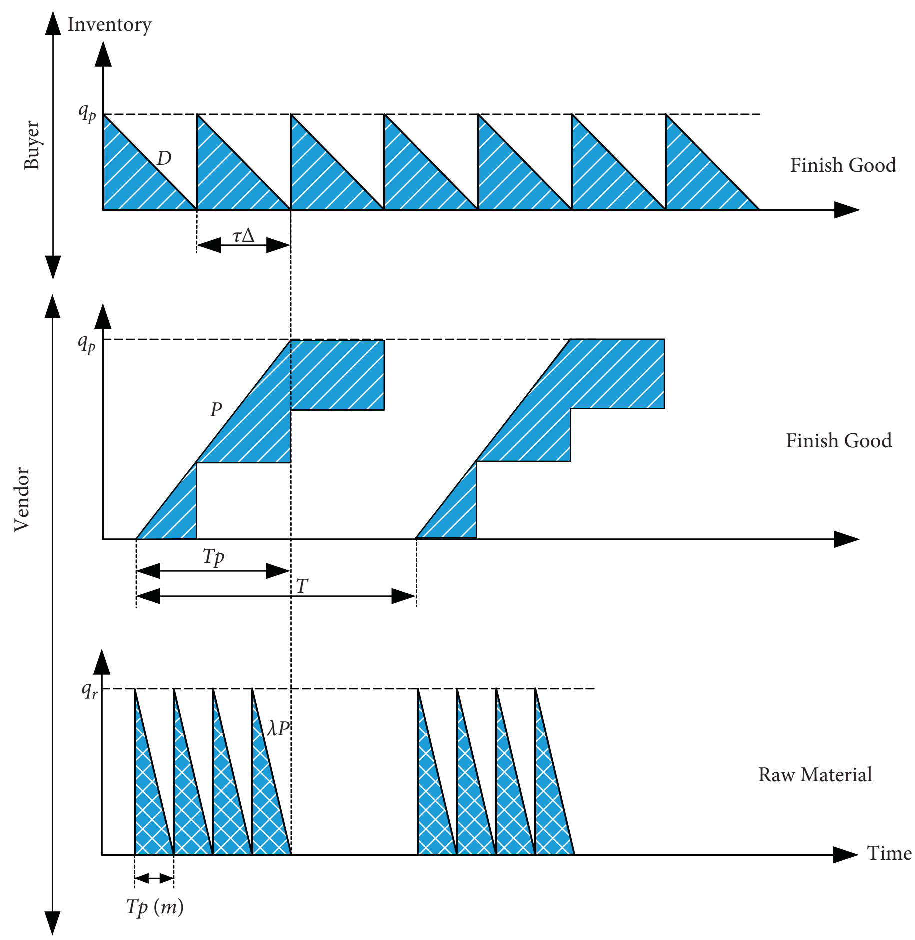

Figure 2: Inventory system on the I-SVSB-IP.

a_p: fixed costs of transportation of the finished product (IDR/order).

d_r: distance of raw material supplier to vendor (manufacture) (km).

d_p: distance from buyer to vendor (manufacture) (km).

v_r: kilometers per liter for the procurement of raw materials (km).

v_p: kilometers per liter for delivery of finished products (km).

βr: the price of fuel used in raw material procurement activities (IDR per liter).

βp: the price of fuel used in the delivery of the finished product (IDR per liter).

Tr: transportation costs for the procurement of raw materials (IDR/order).

Tp: transportation costs for the delivery of the finished product (IDR/order).

S_p: installation costs for processing the finished product (IDR/month).

H_r: raw material storage costs (IDR/unit/month).

H_p: the cost of storing the finished product (IDR/unit/month).

I_{rm}: average raw material inventory at vendors (unit).

I_{pm}: the average finished product inventory at the vendor (unit).

I_{pr}: average finished product inventory at buyers (unit).

τ_{sl}: the expiration time of the finished product (month).

τ_{Start}: the initial time of the deterioration of the finished product (month).

E_i: *batch i* product age when sent to the buyer (month).

R: total income (IDR/month).

p_{max}: maximum product price (IDR/unit).

p_{min}: minimum product price (IDR/unit).

$p(t)$: product price in period t (IDR/unit).

L: total costs due to quality degradation of raw materials (IDR/month).

TC_{rm}: the total cost of the raw material inventory system at the vendor (IDR/month).

TC_{pm}: the total cost of the finished product inventory system at the vendor (IDR/month).

TC_{pr}: the total cost of the finished product inventory system at the buyer (IDR/month).

JTP: the total profit of the integrated inventory system (IDR/month).

m: frequency of ordering raw materials (times/order).

T: time/length during the inventory cycle (month).

n: delivery frequency of finished products to buyers (times/delivery).

5. Mathematical Model

This section describes the proposed mathematical model in the I-SVSB-IP. In the proposed model, the three components of the total cost to be considered include *TCrm, TCpm,* and *TCpr*. At *TCrm*, the cost of an exponential reduction in raw material quality is based on the model proposed by Rong et al. [69]. An illustration of the quality degradation is presented in Figure 3. If $k = 1$, then the quality degradation is exponentially shown by line *B* (first-order reaction). However, if $k = 0$, the quality degradation is linearly represented by line *A* (zero-order reaction). The total quality loss cost model per unit time *L (m, T)* of raw material for all *batches* during one production cycle is presented in (1). Loss quality in the period 0 to *t*, namely, *Qmax* to *Q(t)*, can be denoted by $\Delta Q(t)$ which is presented in (2). The quality level remaining at time *t* is formulated as *Q(t)* in (3).

$$L(m,T) = c_{\text{loss}} \frac{m\lambda P}{T} \int_0^{\lambda \mathrm{DT}/m\lambda P} \Delta Q(t)\mathrm{d}t, \tag{1}$$

$$\Delta Q(t) = Q_{\max}\left(1 - e^{-kt}\right), \tag{2}$$

$$Q(t) = \mathrm{Qmax}\, e^{-kt}. \tag{3}$$

The model for transportation costs in the procurement of raw materials to suppliers is presented in (4). This model considers fixed transportation costs, distance, kilometers per liter, and fuel prices. The average raw material inventory at the vendor (I_{rm}) can be seen in (5). Therefore, the total cost of the raw material inventory system at the vendor (manufacturer) level ($TC_{rm}(m, T)$) is the sum of the costs of purchasing, transportation, inventory, and quality degradation as presented in (6).

$$T_r = a_r + 2 * \frac{d_r}{v_r} * \beta_r, \tag{4}$$

$$I_{rm} = \frac{\lambda D^2 T}{2m\lambda P}, \tag{5}$$

$$\mathrm{TC}_{rm}(m,T) = c_r \lambda\, D + A_r \frac{m}{T} + \left(a_r + 2 * \frac{d_r}{v_r} * \beta_r\right)\frac{m}{T} + H_r \frac{\lambda D^2 T}{2m\lambda P} + c_{\text{loss}} \frac{m\lambda P}{T} \int_0^{\lambda\, DT/m\lambda P} \Delta Q(t)\mathrm{d}t. \tag{6}$$

In the inventory model for finished products at the vendor level, the average finished product inventory at the vendor (I_{pm}) is shown in (7). The total cost of the finished product inventory system at the vendor includes production, setup, and inventory costs which are formulated in (8).

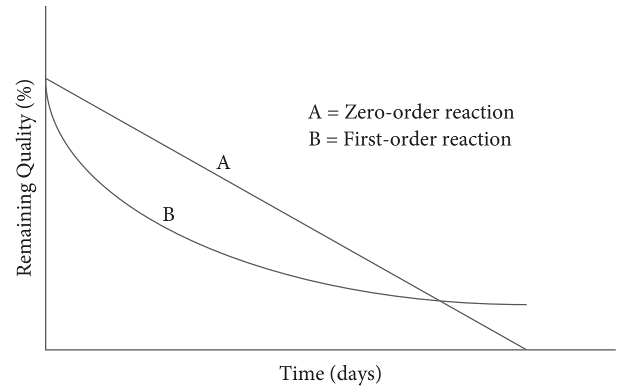

Figure 3: Illustration of product quality degradation.

$$I_{pm} = \frac{\mathrm{DT}}{2n}\left(\frac{D}{P}(2-n) + (n-1)\right), \tag{7}$$

$$\mathrm{TC}_{pm}(n,T) = c_p D + \frac{S}{T} + H_p\left(\frac{\mathrm{DT}}{2n}\left(\frac{D}{P}(2-n) + (n-1)\right)\right). \tag{8}$$

In the total cost of the finished product inventory system at the buyer ($TC_{pr}(n, T)$), the total cost also considers order, purchase, transportation, and inventory costs. The average finished product inventory at buyers (I_{pr}) can be seen in (9). The transportation cost model for the delivery of finished products is formulated in (10). Furthermore, the total cost of the finished product inventory system at the buyer is shown in (11).

$$I_{pr} = \frac{\mathrm{DT}}{2n}, \tag{9}$$

$$T_p = a_p + 2 * \frac{d_p}{v_p} * \beta_p, \tag{10}$$

$$\mathrm{TC}_{pr}(n,T) = c_{\text{sale}} D + A_p \frac{n}{T} + \left(a_p + 2 * \frac{d_p}{v_p} * \beta_p\right)\frac{n}{T} + H_p\left(\frac{\mathrm{DT}}{2n}\right). \tag{11}$$

To model revenue, buyers set prices in three areas. It is based on the customer's willingness to pay for the purchase of a product which will decrease linearly or exponentially as the expiration date approaches [70]. Since the product is sent to the retailer as many as *n* shipments during the production cycle, the quality of the product in each batch may not be the same. The price of the product in each batch is different according to the age of the batch before being shipped. Price function based on the shelf life of each batch is illustrated in Figure 4. The three areas include before quality degradation of the *τStart*, remaining stock sold at a discount, and expired products. The product price for products before quality degradation *τStart* is the maximum price of $p_{\max}$ (region I).

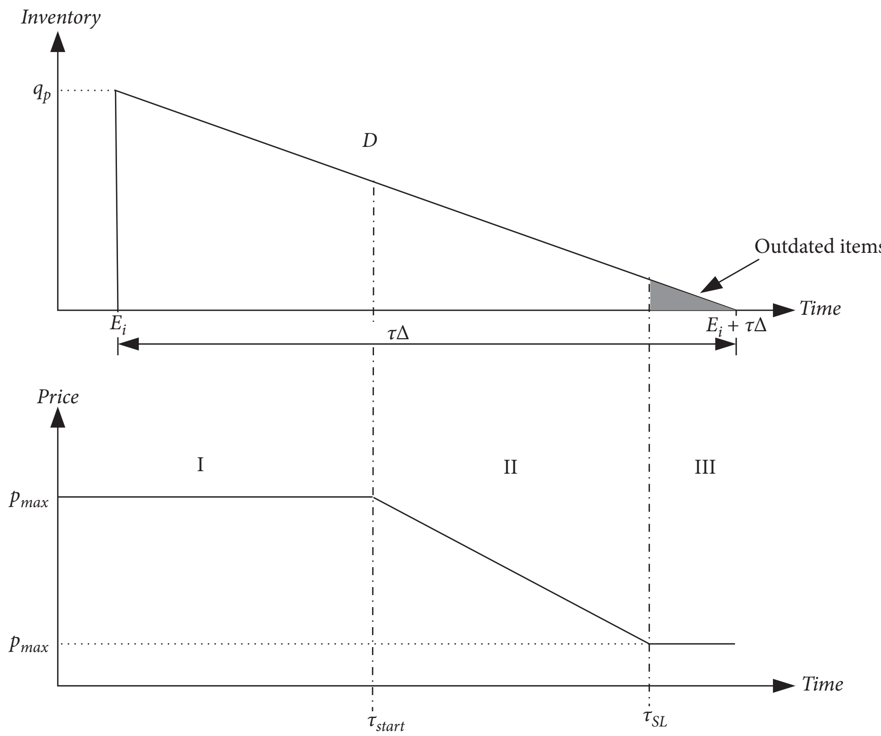

Figure 4: Price function based on the shelf life of each batch.

Discount prices for products are presented in region II. Meanwhile, products that have expired (reaching τ_{sl}) are set at the lowest price of $p_{\min}$ (region III). The price reduction policy is formulated using (12) based on a model proposed by Fauza et al. [29].

$$p(t) = \begin{cases} p_{\max}, \\ p_{\min} + \dfrac{p_{\max} - p_{\min}}{\tau_{sl} - \tau_{\text{start}}} (\tau_{sl} - t), \\ p_{\min}, \\ 0 \leq t < \tau_{\text{Start}}, & \text{region I}, \\ \tau_{\text{Start}} \leq t < \tau_{sl}, & \text{region II}, \\ t \geq \tau_{sl}, & \text{region III}. \end{cases} \tag{12}$$

$$E_i = (i-1)\frac{T}{n} - (i-2)\frac{\text{DT}}{nP}, \tag{13}$$

$$R_i(n,T) = \frac{D}{T} P_{\max} \tau_{\Delta}, \tag{14}$$

$$R_i(n,T) = \frac{D}{T}\left[P_{\max}\left(\tau_{\text{Start}} - E_i\right) + \int_{\tau_{\text{Start}}}^{E_i + \tau_{\Delta}} p(t)\text{d}t\right], \tag{15}$$

$$R_i(n,T) = \frac{D}{T}\left[P_{\max}\left(\tau_{\text{Start}} - E_i\right) + \int_{\tau_{\text{start}}}^{\tau_{sl}} p(t)\text{d}t + p_{\min}\left(E_i + \tau_{\Delta} - \tau_{sl}\right)\right]. \tag{16}$$

Buyers accept *batches* that have *Ei* less than the *τStart* to earn more revenue. The batch age (*Ei*) is denoted in equation (13). Each batch *i* received by the buyer follows the following 3 cases according to the time the product was last consumed ($Ei + \tau\Delta$). When $Ei + \tau\Delta < \tau\text{Start}$, then the revenue per year obtained from this batch can be estimated by equation (14). When $\tau\text{Start} \leq (Ei + \tau\Delta) < \tau\_sl$, the revenue per year from the *batch* is formulated in equation (15). Finally, when $Ei + \tau\Delta \geq \tau sl$, the annual revenue function of this batch is formulated in equation (16).

(17) formulates the Joint Total Revenue in the JTR *(T, n)* system on the I-SVSB-IP. *JTR (T, n)* is formulated as total revenue at the vendor and buyer levels.

$$\text{JTR}(T,n) = c_{\text{sale}} D + \sum_{i=1}^{n} R_i(T,n). \tag{17}$$

Total profit is calculated based on the total revenue ((17) subtracted by the total cost of raw material inventory at the vendor (6), the total cost of finished product inventory at vendor level ((8), and total cost of finished product inventory at buyers (11). Since non-linear integer programming problems are difficult to solve with analytical solutions [9], this study proposes the metaheuristic algorithm to solve the I-SVSB-IP. The mixed-integer non-linear programming model formula for the I-SVSB-IP problem is presented as follows.

Maximize

$$\mathrm{JTP}(m,T,n) = \mathrm{JTR}(T,n) - \left(\mathrm{TC}_{rm}(m,T) + \mathrm{TC}_{pm}(T,n) + \mathrm{TC}_{pr}(T,n)\right), \quad (18)$$

subject to

$$P \geq D, \quad (19)$$

$$E_i < \tau_{\text{start}}; \quad \text{for } i = 1, 2, \ldots n, \quad (20)$$

$$T > 0, \quad (21)$$

$$m,\ n > 0\,(\text{integer number}). \quad (22)$$

The objective function of the I-SVSB-IP inventory model problem to maximize profit formulated in (18) is a form of constraint to ensure that the production level can fulfill all demands shown in (19). The constraint to ensure all batch *i* (*Ei*) arrives at the buyer's warehouse before the initial time of deterioration of the finished product is formulated in equation (20). The constraint to ensure that the decision variable for the time during the inventory cycle (T) is positive is denoted in equation (21). The constraints to ensure that the frequency of raw material orders (m) and the frequency of delivery of finished products to buyers (n) are not zero are presented in equation (22).

6. Proposed Chimp Optimization Algorithm

This section describes the proposed procedure for I-SVSB-IP optimization. Chimp Optimization Algorithm (ChOA) was proposed to optimize this problem. The food hunting behavior of chimpanzees inspired the ChOA algorithm. This algorithm was proposed by Khishe and Mosavi [42]. There were five stages of hunting behavior in chimp, namely, prey drive and chase, attack method (exploitation stage), prey attacking (utilization), prey search (exploration), and social incentive (sexual motivation). From this behavior, the prey was mainly hunted at the exploration and exploitation stage. (19) and (20) formulated the drive and chasing behavior, where *iter* was the number of iterations; *a, mc,* and *c* were the coefficient vectors; x_{prey} was the prey position vector; and x_{chimp} was the chimp position vector. The coefficient vectors *a, mc,* and *c* were calculated by, and (21)–(23). The value of f decreased non-linearly from 2.5 to 0 through the iteration process. r_1 and r_2 were random vectors in the range [0.1]. *mc* was a chaotic vector calculated based on various chaotic maps that represented chimpanzee sexual motivation in the hunting process.

$$d = \left|c.x_{\text{prey}}(\text{iter}) - mc.x_{\text{chimp}}(\text{iter})\right|, \quad (23)$$

$$x_{\text{chimp}}(\text{iter}+1) = x_{\text{prey}}(\text{iter}) - a.d, \quad (24)$$

$$a = 2.f.r_1 - f, \quad (25)$$

$$c = 2.r_2, \quad (26)$$

$$mc = \text{Chaotic\_value}. \quad (27)$$

Chimps have a unique hunting behavior. The attacker chimp usually carries out the hunting process. The drivers, barriers, and chaser chimps sometimes participate in hunting for prey. To mathematically formulate chimp behavior, it is assumed that the attacker chimp is the best available solution. The drivers, barriers, and chaser chimps know better about potential prey locations. x_{Attacker} is the best search agent. x_{Chaser} is the second-best search agent. x_{Barrier} is the third-best search agent, and x_{Driver} is the fourth-best search agent. The other chimps are forced to renew their positions based on that solution according to the best chimpanzee location. This relationship is represented in (28), (29), and (30).

$$\begin{aligned} d_{\text{Attacker}} &= \left|c_1 x_{\text{Attacker}} - mc_1.x\right|, \\ d_{\text{Barrier}} &= \left|c_2.x_{\text{Barrier}} - mc_2.x\right|, \end{aligned} \quad (28)$$

$$\begin{aligned} d_{Chaser} &= \left|c_3 x_{Chaser} - mc_3.x\right| \\ d_{\text{Driver}} &= \left|c_4 x_{\text{Driver}} - m_4 cx\right|, \\ x_1 &= x_{\text{Attacker}} - a_1\left(d_{\text{Attacker}}\right), \\ x_2 &= x_{\text{Barrier}} - a_2\left(d_{\text{Barrier}}\right), \end{aligned} \quad (29)$$

$$\begin{aligned} x_3 &= x_{\text{Chaser}} - a_3\left(d_{\text{Chaser}}\right), \\ x_4 &= x_{\text{Driver}} - a_4\left(d_{\text{Driver}}\right), \\ x(\text{iter}+1) &= \frac{x_1 + x_2 + x_3 + x_4}{4}. \end{aligned} \quad (30)$$

The chimps attack the prey and finish the hunt as soon as the prey stops moving. To mathematically model the attack process, the values of *f* and *a* have decreased. The value of *a* is a random variable in the interval $[-2f, 2f]$. With each additional iteration, the value of *f* decreases from 2.5 to 0. If the random value of *a* is in the range [-1.1], then the next chimpanzee position can be in any location.

This algorithm assumed a 50% chance of a chimp choosing between the normal position update mechanism or the random model. This behavior was formulated in (31), where μ was a random number in [0, 1]. Chaotic$_{\text{-value}}$ was based on the formula proposed by Khishe and Mosavi [42]. The complete procedure of the proposed algorithm is presented in Algorithm 1.

$$x_{\text{chimp}}(t+1) = \begin{cases} x_{\text{prey}}(t) - a.d, & \text{if } \mu < 0.5, \\ \text{Chaotic}_{\text{-value}}, & \text{if } \mu > 0.5\,. \end{cases} \quad (31)$$

The ChOA applied by Goyal [47] is an algorithm used to solve continuous problems. As presented in Section 3, the I-SVSB-IP was categorized as mixed-integer non-linear programming. The I-SVSB-IP model was optimized based on the objective function of maximizing the Joint Total Profit. The decision variables of this problem were the inventory cycle time (T), the frequency of raw material orders (m), and the frequency of delivery of the finished product to the buyer (n). The time decision variable during the inventory cycle (T) was a real number. However, the decision variables for the frequency of delivery of the finished product to the buyer (n) and the frequency of ordering raw material

Initialize the chimp population xi ($i = 1, 2, \ldots, n$)
Initialize **f, mc, a** and **c**
Calculate the position of each chimp
Divide chimps randomly into independent groups
Until stopping condition is satisfied
Calculate the JTP of each chimp using (18)
x_{Attacker} = *the best search agent*
x_{Chazer} = *the second-best search agent*
x_{Barrier} = *the third-best search agent*
x_{Driver} = *the fourth-best search agent*
  while ($t <$ maximum number of iterations)
    for each chimp:
      Extract the chimp's group
      Use its group strategy to update f, m and c
      Use **f**, **mc** and **c** to calculate **a** and then **d**
  end for
    for each search chimp
      if ($\mu < 0.5$) if ($|a| < 1$)
    Update the position of the current search agent using (20)
      else if ($|\mathbf{a}|>1$)
        Select a random search agent
      end if
    else if ($\mu > 0.5$)
  Update the position of the current search using (31)
    end if
  end for
Update **f, mc, a** and **c**
Update $x_{\text{Attacker}}, x_{\text{ADriver}}, x_{\text{Barrier}}, x_{\text{Chazier}}$
$t = t + 1$
end while
return x_{Attacker}

ALGORITHM 1: Chimp Optimization Algorithm (ChOA).

(m) were integer numbers. This study proposed a conversion procedure from real numbers to integers for the decision variables m and n. Figure 5 shows an illustration of the decision variable conversion. If the decimal values of m and $n < 0.5$, then the whole number will be rounded down. Conversely, if the decimal values of m and $n \geq 0.5$, then the rounded number will be rounded up.

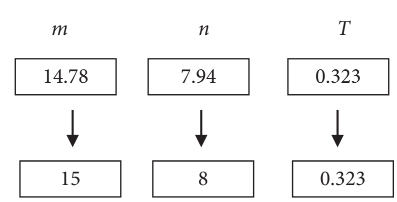

FIGURE 5: Illustration of decision variable conversion.

7. Experimental Data and Procedure

7.1. Case Study. This study used data from a case study of a food company in Indonesia. The data collected were as follows: $P = 1418$ kg/month, $D = 1298$ kg/month, $\lambda = 7.2$, Closs = 7,200 IDR/kg, Csale = 85,000 IDR/kg, $Cr = 7{,}200$ IDR/kg, $Cp = 550$ IDR/kg, $Ar = 50{,}000$ IDR/order, $Ap =$ 50,000 IDR/order, $Sp = 60{,}000$ IDR/installation, $Hr = 520$ IDR/(kg/month), $Hp = 528$ IDR/(kg/month), $P\text{max} =$ 105,000 IDR/kg, $P\text{min} = 0$ IDR/kg, $Ar = 10{,}000$ IDR/order, $Ap = 10{,}000$ IDR/order, $Dr = 20$ km, $Dp = 30$ km, $vr = 7$ km, $vp = 8$ km, $\beta r = 7{,}650$ IDR/liter, $\beta p = 7{,}650$ IDR/liter, $k = 0, 5$, $\tau sl = 8$ months, and $\tau\text{Start} = 6$ months.

7.2. Experimental Procedure. This section describes the experimental procedure on the I-SVSB-IP model. In optimization with the ChOA, this experiment exercised 100 search agents as the population and 100 iterations. The three dimensions used in the ChOA were the frequency of delivery of the finished product (n), the frequency of ordering raw materials (m), and the time of the production cycle (T). The upper and lower limits were used as the value limits for the decision variables. The values for the upper and lower bounds of n and m had a range of 1 to 100. Furthermore, T's values for the upper and lower bounds were real numbers ranging from 0 to 1.

The optimization results with ChOA were compared with state-of-the-art algorithms such as GA, PSO, and SA. In the GA, the parameters used were population = 100, iteration = 100, crossover rate = 0.7, and mutation = 0.2. For the PSO algorithm, the parameters used were particle = 100, iteration = 100, and inertia weight = 0.5. Furthermore, the HS parameter used population = 100 and iteration = 100.

This comparison was used to test the performance of the proposed algorithm.

The decision variables from the optimization of the I-SVSB-IP model with ChOA were used as sensitivity analyses. There were two parts of the sensitivity analysis, including (1) the influence of the variables *m, n, T,* and *k* on cost, revenue, and Joint Total Profit and (2) the influence of transportation variables *(ar, ap, dr, dp, vr, vp, βr, βp)* on cost, revenue, and Joint Total Profit. In the sensitivity analysis, each variable *m, n, T,* and *k* was treated in 9 different experiments. Furthermore, seven experiments were conducted on each transport variable (ar, ap, dr, dp, vr, vp, βr, βp). These sensitivity analyses were used to determine the effect of variables on *JTP, TCrm, TCpm, TCpr*, and *JTR* in the I-SVSB-IP model.

8. Results and Discussion

8.1. Optimization with ChOA and Comparison of Algorithms. The results of I-SVSB-IP optimization with ChOA can be seen in Table 2. These findings indicated that the resulting Joint Total Profit is 65,232,000 IDR. Based on the ChOA optimization results, the raw material delivery frequency (*m*) was 15 times, the finished product delivery frequency (*n*) was 3 times, and the production cycle time (*T*) was 0.871 months. The results of the comparison of the algorithms are presented in Figure 6. The experimental results showed that the proposed ChOA provides more optimal results than the GA, PSO, and HS algorithms.

Table 2: Results of I-SVSB-IP optimization with ChOA.

Optimization by ChOA	Decision variable		
	m	*n*	*T*
	15	3	0.871
	Vendor	Buyer	Total
Total cost (IDR)	69,833,000	110,660,000	180,493,000
Total revenue (IDR)	110,330,000	136,290,000	246,620,000
Joint Total Profit (IDR)		65,232,000	

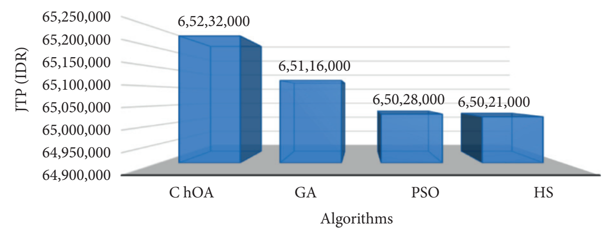

Figure 6: Comparison of algorithms.

8.2. Sensitivity Analysis towards m, n, T, and k. The sensitivity analysis results of the effect of *m* on cost, revenue, and profit are presented in Table 3. These results indicated that changes in the value of *m* do not affect *TCpm, TCpr*, and *JTR*. Furthermore, when *m* is increased from the optimal value (15), the *JTP* increases, and *TCrm* decreases. Conversely, if *m* is derived from the optimal value (15), then *JTP* decreases, and *TCrm* increases. This result is reasonable because the raw material has exponential quality degradation, so the higher the *m*, the lower the cost.

The sensitivity analysis results of *n* on cost, revenue, and profit are presented in Table 4. These results projected that changes in the value of *n* do not affect *TCrm, TCpr, and JTR*. Furthermore, when *n* is increased from the optimal value (3), the *JTP* and *TCrm* decrease further. Conversely, if *n* is derived from the optimal value (3), *JTP* decreases, while *TCrm* increases.

The sensitivity analysis of the effect of *T* on cost, revenue, and profit is presented in Table 5. These results suggested that changes in the value of *T* do not affect *JTR*. Furthermore, increasing *T* from the optimal value (0.871) decreases *JTP* while increasing *TCrm*, *TCpm*, and *TCpr*. Conversely, when *T* is reduced from its optimal value (0.871), *JTP* decreases while *TCrm*, *TCpm*, and *TCpr* increase.

The sensitivity analysis of the effect of *k* on cost, revenue, and profit is shown in Table 6. These results interpreted that changes in the value of *k* do not affect *TCpm, TCpr,* and *JTR*. In addition, when *k* increases, *JTP* would certainly decrease, and *TCrm* increases. Conversely, when *k* decreases, *JTP* increases, and *TCrm* decreases.

*8.3. Sensitivity Analysis of Transportation Variables (***ar***,* **ap***,* **dr***,* **dp***,* **vr***,* **vp***, β***r***, β***p***).* Table 7 indicates the sensitivity analysis of the effect of ar on cost, revenue, and profit. These results asserted that when *ar* costs increase, *JTP* decreases and *TCrm* increases. In contrast, the lower the *ar* cost, the higher *JTP* and the lower *TCrm*. The increase and decrease in *ar* value do not affect *TCpm, TCpr,* and *JTR*. Analysis of the sensitivity of ap on cost, revenue, and profit is shown in Table 8. The results suggested that changes in the value of *ap* affect the value of *JTP* and *TCpr*. Increased ap results in a decrease in *JTP* and an increase in *TCpr*. The *ap* cost changes do not affect *TCrm*, *TCpm*, and *JTR*.

The sensitivity analysis of the effect of dr on cost, revenue, and profit is shown in Table 9. These results confirmed that the greater the value of dr, the smaller the value of *JTP* and the greater the *TCrm*. Changes in the value of *dr* do not affect *TCpm*, *TCpr*, and *JTR*. Table 10 displays the sensitivity analysis of the effect of *dp* on cost, revenue, and profit. These results illustrated that the greater the *dp* value, the lower the *JTP* value and the higher the *TCpr* value. The *dp* variable does not affect *TCrm*, *TCpm*, and *JTR*.

The sensitivity analysis of the effect of *vr* on cost, revenue, and profit is shown in Table 11. The table demonstrates that as *vr* increases, the value of *JTP* increases and *TCrm* decreases. Changes in the *vr* value do not affect *TCpm, TCpr*, and *JTR*. Table 12 shows the sensitivity analysis of the effect of *vp* on cost, revenue, and profit. The analysis results stated that when the *vp* is increased, the *JTP* value is higher and the *TCpr* value decreases.

Table 13 presents the results of the influence of *βr* on cost, revenue, and profit. These findings explained that as the *βr* increases, the *JTP* decreases and the *TCrm* increases. The

Table 3: Sensitivity analysis of the effect of m on cost, revenue, and profit.

m	n	T	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
10	3	0.871	64,764,000	70,301,000	895,000	110,660,000	246,620,000
11	3	0.871	64,913,000	70,152,000	895,000	110,660,000	246,620,000
12	3	0.871	65,028,000	70,037,000	895,000	110,660,000	246,620,000
13	3	0.871	65,116,000	69,949,000	895,000	110,660,000	246,620,000
14	3	0.871	65,183,000	69,882,000	895,000	110,660,000	246,620,000
15	**3**	**0.871**	**65,232,000**	**69,833,000**	**895,000**	**110,660,000**	**246,620,000**
16	3	0.871	65,268,000	69,797,000	895,000	110,660,000	246,620,000
17	3	0.871	65,293,000	69,772,000	895,000	110,660,000	246,620,000
18	3	0.871	65,307,000	69,758,000	895,000	110,660,000	246,620,000
19	3	0.871	65,314,000	69,751,000	895,000	110,660,000	246,620,000

Table 4: Analysis of the sensitivity of the effect of n on cost, revenue, and profit.

m	n	T	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
15	1	0.871	65,021,000	69,833,000	1,056,000	110,710,000	246,620,000
15	2	0.871	65,214,980	69,833,000	932,020	110,640,000	246,620,000
15	**3**	**0.871**	**65,232,000**	**69,833,000**	**895,000**	**110,660,000**	**246,620,000**
15	4	0.871	65,197,000	69,833,000	870,000	110,720,000	246,620,000
15	5	0.871	65,149,000	69,833,000	858,000	110,780,000	246,620,000
15	6	0.871	65,087,000	69,833,000	850,000	110,850,000	246,620,000
15	7	0.871	65,023,000	69,833,000	844,000	110,920,000	246,620,000
15	8	0.871	64,948,000	69,833,000	839,000	111,000,000	246,620,000
15	9	0.871	64,881,000	69,833,000	836,000	111,070,000	246,620,000
15	10	0.871	64,814,000	69,833,000	833,000	111,140,000	246,620,000

Table 5: Sensitivity analysis of the effect of T on cost, revenue, and profit.

m	n	T	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
15	3	0.2	62,437,000	71,764,000	1,039,000	111,380,000	246,620,000
15	3	0.3	64,037,000	70,582,000	951,000	111,050,000	246,620,000
15	3	0.4	64,734,000	70,082,000	914,000	110,890,000	246,620,000
15	3	0.5	65,070,638	69,856,000	896,000	110,797,362	246,620,000
15	3	0.6	65,226,000	69,765,000	889,000	110,740,000	246,620,000
15	3	0.7	65,281,000	69,752,000	887,000	110,700,000	246,620,000
15	**3**	**0.871**	**65,232,000**	**69,833,000**	**895,000**	**110,660,000**	**246,620,000**
15	3	0.9	65,213,000	69,855,000	892,000	110,660,000	246,620,000
15	3	1	65,128,651	69,944,000	898,000	110,649,349	246,620,000

Table 6: Sensitivity analysis of the effect of k on cost, revenue, and profit.

k	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
0.1	66,638,000	68,427,000	895,000	110,660,000	246,620,000
0.2	66,460,000	68,605,000	895,000	110,660,000	246,620,000
0.3	66,283,000	68,782,000	895,000	110,660,000	246,620,000
0.4	66,106,000	68,959,000	895,000	110,660,000	246,620,000
0.5	**65,930,000**	**69,135,000**	**895,000**	**110,660,000**	**246,620,000**
0.6	65,755,000	69,310,000	895,000	110,660,000	246,620,000
0.7	65,580,000	69,485,000	895,000	110,660,000	246,620,000
0.8	65,406,000	69,659,000	895,000	110,660,000	246,620,000
0.9	65,232,000	69,833,000	895,000	110,660,000	246,620,000
1	65,059,000	70,006,000	895,000	110,660,000	246,620,000

Table 7: Analysis of sensitivity to the effect of *ar* on cost, revenue, and profit.

ar	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
8500	65,258,000	69,807,000	895,000	110,660,000	246,620,000
9000	65,250,000	69,815,000	895,000	110,660,000	246,620,000
9500	65,241,000	69,824,000	895,000	110,660,000	246,620,000
10000	65,232,000	69,833,000	895,000	110,660,000	246,620,000
10500	65,224,000	69,841,000	895,000	110,660,000	246,620,000
11000	65,215,000	69,850,000	895,000	110,660,000	246,620,000
11500	65,207,000	69,858,000	895,000	110,660,000	246,620,000

Table 8: Sensitivity analysis of the effect of *ap* on cost, revenue, and profit.

ap	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
8500	65,237,000	69,833,000	895,000	110,655,000	246,620,000
9000	65,235,000	69,833,000	895,000	110,657,000	246,620,000
9500	65,233,000	69,833,000	895,000	110,659,000	246,620,000
10000	65,232,000	69,833,000	895,000	110,660,000	246,620,000
10500	65,230,000	69,833,000	895,000	110,662,000	246,620,000
11000	65,228,000	69,833,000	895,000	110,664,000	246,620,000
11500	65,227,000	69,833,000	895,000	110,665,000	246,620,000

Table 9: Sensitivity analysis of the influence of *dr* on cost, revenue, and profit.

dr	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
5	65,797,000	69,268,000	895,000	110,660,000	246,620,000
10	65,609,000	69,456,000	895,000	110,660,000	246,620,000
15	65,421,000	69,644,000	895,000	110,660,000	246,620,000
20	65,232,000	69,833,000	895,000	110,660,000	246,620,000
25	65,044,000	70,021,000	895,000	110,660,000	246,620,000
30	64,856,000	70,209,000	895,000	110,660,000	246,620,000
35	64,668,000	70,397,000	895,000	110,660,000	246,620,000

Table 10: Sensitivity analysis of dp effect on cost, revenue, and profit.

dp	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
15	65,322,000	69,833,000	895,000	110,570,000	246,620,000
20	65,292,000	69,833,000	895,000	110,600,000	246,620,000
25	65,262,000	69,833,000	895,000	110,630,000	246,620,000
30	65,232,000	69,833,000	895,000	110,660,000	246,620,000
35	65,192,000	69,833,000	895,000	110,700,000	246,620,000
40	65,162,000	69,833,000	895,000	110,730,000	246,620,000
45	65,132,000	69,833,000	895,000	110,760,000	246,620,000

Table 11: Sensitivity analysis of the effect of *vr* on cost, revenue, and profit.

vr	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
4	64,668,000	70,397,000	895,000	110,660,000	246,620,000
5	64,931,000	70,134,000	895,000	110,660,000	246,620,000
6	65,107,000	69,958,000	895,000	110,660,000	246,620,000
7	65,232,000	69,833,000	895,000	110,660,000	246,620,000
8	65,326,000	69,739,000	895,000	110,660,000	246,620,000
9	65,400,000	69,665,000	895,000	110,660,000	246,620,000
10	65,458,000	69,607,000	895,000	110,660,000	246,620,000

Table 12: Sensitivity analysis of the effect of vp on cost, revenue, and profit.

vp	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
5	65,112,000	69,833,000	895,000	110,780,000	246,620,000
6	65,162,000	69,833,000	895,000	110,730,000	246,620,000
7	65,202,000	69,833,000	895,000	110,690,000	246,620,000
8	65,232,000	69,833,000	895,000	110,660,000	246,620,000
9	65,252,000	69,833,000	895,000	110,640,000	246,620,000
10	65,262,000	69,833,000	895,000	110,630,000	246,620,000
11	65,282,000	69,833,000	895,000	110,610,000	246,620,000

Table 13: Sensitivity analysis of the effect of βr on cost, revenue, and profit.

βr	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
4650	65,528,000	69,537,000	895,000	110,660,000	246,620,000
5650	65,429,000	69,636,000	895,000	110,660,000	246,620,000
6650	65,331,000	69,734,000	895,000	110,660,000	246,620,000
7650	65,232,000	69,833,000	895,000	110,660,000	246,620,000
8650	65,134,000	69,931,000	895,000	110,660,000	246,620,000
9650	65,036,000	70,029,000	895,000	110,660,000	246,620,000
10650	64,937,000	70,128,000	895,000	110,660,000	246,620,000

Table 14: Sensitivity analysis of the effect of βp on cost, revenue, and profit.

βp	JTP (IDR)	TCrm (IDR)	TCpm (IDR)	TCpr (IDR)	JTR (IDR)
4650	65,302,000	69,833,000	895,000	110,590,000	246,620,000
5650	65,282,000	69,833,000	895,000	110,610,000	246,620,000
6650	65,252,000	69,833,000	895,000	110,640,000	246,620,000
7650	65,232,000	69,833,000	895,000	110,660,000	246,620,000
8650	65,202,000	69,833,000	895,000	110,690,000	246,620,000
9650	65,172,000	69,833,000	895,000	110,720,000	246,620,000
10650	65,152,000	69,833,000	895,000	110,740,000	246,620,000

value of βr does not affect *TCpm, TCpr*, and *JTR*. Sensitivity analysis of the effect of βp on cost, revenue, and profit is shown in Table 14. From the analysis, it can be concluded that the greater the βp, the smaller the *JTP* and the greater the *TCpr*. The value of βp does not affect *TCrm*, *TCpm,* and *JTR*.

8.4. Managerial Implications. According to the findings of this study, managing production levels has a significant impact on the operational cost and profit of the built models. The company's middle management relies on this information to forecast demand accurately. It could be done by applying Collaborative Planning, Forecasting, and Replenishment (CPFR). It can improve supply chain management performance at various levels of the supply chain, including manufacturing [71], vendor-managed inventory [72], and supplier [73, 74]. In addition, the CPFR ensures that the vocal companies and their supply chain partners have the same accurate information about demand. When all chain partners work together, they will put forth their best effort to meet demand [75].

The study also found a relation between the financial performance of the company and the length of the product's deterioration date. The result of this research show that the shorter the product's expiration date when delivered to retailers, the higher the revenue loss. As a result, management should give warehousing management a higher priority. Some warehousing methods use the expiration date of a product as a basis for arranging deliveries to retailers. For example, FEFO (First Expired First Out) warehousing management classification ensures that products are delivered based on their expiration date [76].

This study also found that a decrease in the quality of raw materials impacts a company's profits. It demonstrates that factors like temperature, air circulation, and storage conditions significantly impact the quality of food raw materials. Temperature and humidity have been shown to significantly impact the quality of perishable materials and products [77]. Since raw materials are delivered to different parties, a traceability system must be implemented to ensure that they' have all received the proper treatment. Before being delivered, raw material from previous processes should be labeled with temperature, humidity, and storage conditions information. The alternative method for ensuring the safety and quality of raw materials and finished goods would be tracking and tracing system information [78].

Another interesting finding is that the supplier-manufacturer and manufacturer-retailer distance affects the company's costs and profits. As a product with perishable characteristics, transportation activities affect the quality of food products [79]. Determining the correct route can reduce transportation costs, especially fuel costs [79–81]. Therefore, choosing the supplier-manufacturing and manufacturing-retailer transportation route needs to be a concern for company management to minimize costs and increase profits.

9. Conclusion

This study was conducted to develop an I-SVSB-IP model that considers exponential quality degradation of raw materials. The proposed model also involves transportation costs. This study succeeded in developing the I-SVSB-IP model with the ChOA as an optimization tool. The experimental results suggested that the ChOA can solve the I-SVSB-IP. In addition, the proposed ChOA has a better performance than GA, PSO, and HS. Sensitivity analysis to the decision variables m, n, T, and k and transportation variables was also thoroughly presented. This study had limitations, including the demand for finished products, which was assumed to be deterministic and static. In addition, it was assumed that the load did not affect the fuel consumption. In further research, the demand for finished products needs to consider dynamic and probabilistic characteristics. It is seen necessary to consider the load in the estimation of fuel consumption in transportation costs.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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