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Integrated Multi-Vendor Single-Buyer Inventory System Model in Textile Waste Processing Industry

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A B S T R A C T

PT. Superbtex Nonwoven Division is one of the industries implementing a green manufacturing system in Bandung by using textile solid waste as raw material and processing it into value-added finished products. However, the solid waste generated by consumers and garment factories is very large and cannot be accommodated in its entirety by PT. Superbtex Nonwoven Division. Another problem arises in terms of inventory both for vendors and buyers; delivering waste from vendors to buyers in small quantities and frequently can lower inventory costs for buyers, but concurrently raise transportation expenses for vendors, and vice versa. Therefore this research was conducted to solve the problem of an integrated multi vendor-single buyer inventory system that considers independent transportation, sorting, and disposal to find the minimum total system cost by finding the optimal value of order lot size, delivery frequency, and proportion of order lot size. that each vendor needs to send to the buyer. Problem-solving is done using the Mixed Integer Non Linear Programming (MINLP) method with the LINGO 18.0 solver. The results obtained from this study stated that the sorting costs at vendor 1 (S_1), the sorting costs at the buyer (Sb), the transportation variable costs (Fy), the delivery truck capacity (X), and the demand rate (D) have a significant effect to changes in total system cost (TC). So that the five parameters need to be estimated carefully to determine the optimal system cost.

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1. INTRODUCTION

Fashion refers to appearance encompassing accessories, bags, shoes, makeup, hairstyles, and most importantly, clothing. Nowadays, fashion is not merely a primary need, but it has become an artistic requirement that drives the rapid growth of this industry (Setiawan & Sesilia, 2019). The rapid development of the fashion industry and the manufacturing of various corporate organizations are increasingly stringent in global competition (Syaputra & Aisyah, 2022). However, alongside the significant benefits gained from the development of the fashion industry in Indonesia, there are negative impacts in terms of waste that need to be addressed (Amaranti. R. et al., 2017). The fashion industry itself is one of the largest contributors of solid textile waste, which greatly affects the environment. About 65 million tons of waste are produced in Indonesia every day and around 15 million tons of waste still pollutes the environment and ecosystem, because it is not handled and processed (Setyaningrum et al., 2022).

The global demand for environmental aspects has led to the emergence of green manufacturing or green production systems (Saptaningtyas, 2016). Consequently, several industries, including the textile industry, have begun implementing the concept of green manufacturing in their business processes. The example of this condition is PT. Superbtex Nonwoven Division applies green manufacturing principles in its production process by utilizing fabric waste as a raw material that is then recycled into new products with commercial value. Therefore, Green Manufacturing has become a desirable condition in long-term purchasing agreements in the textile industry (Susanti, 2017).

Just-in-Time (JIT) delivery is another factor in long-term purchasing agreements aimed at minimizing inventory costs for the buyer (Chen & Sarker, 2014). From an inventory perspective, the buyer's costs will decrease if the vendor makes relatively frequent deliveries (Just-in-Time). However, this will increase transportation costs by the vendor (Glock & Kim, 2014). In the earlier literature, the integrated vendor-buyer models did not consider transportation issues (Glock, 2012). However, in practice, transportation costs play a crucial role in JIT procurement and production. Since JIT emphasizes small lot sizes with frequent deliveries, it inevitably leads to increased transportation costs, making minimal transportation costs vital for the successful implementation of JIT philosophy (Chen & Sarker, 2014).

In addition, supply-related issues often considered in multi-echelon integrated inventory models, such as multi-vendor single-buyer with single-item or multi-item considerations, involve selecting the right vendor to support the model (Kumar et al., 2017). According to Ware et al. in Kumar et al., 2017, vendor capacity, quality level, lead time, and various cost parameters such as unit holding costs, transportation costs, and others (Kumar et al., 2017) are the buyer's considerations in choosing the appropriate vendor.

PT. Superbtex Nonwoven Division, as the buyer, is considering accepting solid textile waste as raw material from two vendors: waste from garment factories and waste collected by collectors. However, due to the large amount of waste generated, PT. Superbtex Nonwoven Division, as a waste processing industry, cannot accommodate the entire waste. Optimal delivery frequency is crucial to achieving the lowest system cost. Minimizing the total cost required to complete a series of jobs is one the efforts made to ensure customer satisfaction (Lumban Raja, 2022)

Based on the explanation above, the purpose of this research is to assist the textile waste processing industry in minimizing the total system cost by presenting a deterministic model for a single item that considers transportation costs (fixed and variable), inventory costs, sorting costs, and disposal costs in a multi-vendor single-buyer integrated inventory system using two vendors: collectors and garment industries. The research aims to determine the production policy for ordering lot sizes, the proportion of order lot sizes fulfilled by vendors, and the optimal waste delivery frequency from the vendor.

2. LITERATURE REVIEW

A vendor is a company that provides raw materials, components, or services to another company as a buyer. Each company has its approach or way to increase the productivity of its company (Prabowo & Aisyah, 2020). Choosing the right vendor is a fundamental strategy to improve the product quality of any company. In the current manufacturing environment for the supply chain, the right vendor can deliver quality products in the required quantities at reasonable prices before the predetermined delivery schedule (Kumar et al., 2017). There are several methods proposed

in vendor selection based on different evaluation indicators such as quality, delivery schedule, and past performance (Lehmann and O'Shaughnessy, 1982), vendor's technological capabilities, financing abilities (Goffin et al., 1997), vendor capabilities and performance (Narasimhan et al., 2001), vendor's natural resource condition, life cycle costs (Noci, 1997), and others (Kumar et al., 2017).
In vendor selection problems, quantitative models mainly focus on the question of which vendor to choose and how to allocate order quantities to vendors (Kumar et al., 2017). The first integrated inventory model considering multiple buyers (multi-buyer) was proposed by Joglekar and Tharthare (1990), who studied vendors supplying products to a group of identical buyers. This model was extended by Banerjee and Burton (1994), who considered heterogeneous buyers and used a common delivery cycle where the beginning vendor supplies to all buyers to coordinate the system. With the help of a common delivery cycle, separate and uneven depletion of vendor inventories that can result in shortages on the vendor side can be avoided (Kumar et al., 2017).

On the other hand, one of the integrated inventory models considering more than one vendor is the study by Kim and Goyal in Kumar et al. (2017), which examined a system with multi-vendor single-buyer (MVSB). This paper compared two different delivery structures where all vendors deliver their production lots simultaneously or vendors deliver them sequentially, with vendor 1 delivering its product after vendor 2's product has been depleted. They studied the impact of different parameter values on the allocation of order quantities to vendors and the total system cost.

Another model was proposed by Hong and Hayya (1992), which considered a just-in-time scenario where the buyer intends to reduce its lot size, either by placing larger orders in multiple shipments or by allocating order quantities to multiple vendors. Glock (2011) addresses vendor selection and lot sizing decision problems in the MVSB environment, where the buyer obtains products from heterogeneous vendors, aiming to minimize the total system cost. (Glock, 2012) presents a comprehensive review of the published literature on the Joint Economic Lot Size (JELS) model and accurately categorizes and synthesizes existing works in this area. The study by Kumar et al. (2017) extends the Glock (2011) model by investigating shipment consolidation in the integrated inventory model, assuming that each vendor cannot meet the entire buyer's demand, resulting in shortages. It assumes that the buyer replenishes inventory from multiple vendors, where each vendor provides its own production, which may occur by avoiding overlapping delivery cycles (as shown in Table 1).

On the other hand, the research conducted by the author is carried out at PT. Superbtex Nonwoven Division, which acts as the buyer and uses fabric waste as raw material sourced from 2 vendors, namely garment factories and consumer waste collected by collectors. Therefore, it employs the MVSB integrated inventory model and assumes that vendors individually deliver their waste directly to the buyer without involving third parties. The waste used as raw material comes in various types, necessitating a sorting process to facilitate the production process and improve product quality. Hence, this study assumes the existence of non-recyclable waste materials, which require sorting and disposal processes. The system overview of the issues and the production process flow at PT. Superbtex Nonwoven Division can be seen in Fig. 1.

Table 1. State of The Art (SoTA)

Information	Glock (2011)	Chen & Sarker (2014)	Kumar et al. (2017)	Suryana (2020)	This Research
Model	EOQ	EOQ	EOQ	EOQ	EOQ
Scope	Single Item Multi Vendor-Single Buyer	Single Item Multi Vendor-Single Buyer	Single Item Multi Vendor-Single Buyer	Single Item Single Vendor-Single Buyer	Single Item Multi Vendor-Single Buyer

Information	Glock (2011)	Chen & Sarker (2014)	Kumar et al. (2017)	Suryana (2020)	This Research
	Shortage not allowed	Shortage not allowed	Shortage allowed	Shortage not allowed	Shortage not allowed
	Independent transportation	Shared transportation	Independent transportation	Independent transportation	Independent transportation (divided into fix and variable cost)
	Demand deterministic	Demand deterministic	Demand deterministic	Demand deterministic	Demand deterministic
	Demand > Production	Production > Demand	Demand > Production	Production > Demand	Demand > Production
	Sorting and disposal waste process are not considered	Sorting and disposal waste process are not considered	Sorting and disposal waste process are not considered	Sorting and disposal waste process are considered	Sorting and disposal waste process are considered
Considered Costs	Inventory, transportation, order	Inventory, transportation (TPL)	Inventory, transportation, order, shortage	Inventory, transportation, sorting, disposal	Inventory, transportation, sorting, disposal, order
Decision Variable	Delivery frequency, order lot size, the proportion of order lot sizes produced by vendors	Delivery frequency, production lot size at vendors, production lot size at buyer	Delivery frequency, order lot size, production quantity by vendors	Delivery frequency, order lot size	Delivery frequency, order lot size, the proportion of order lot sizes produced by vendors

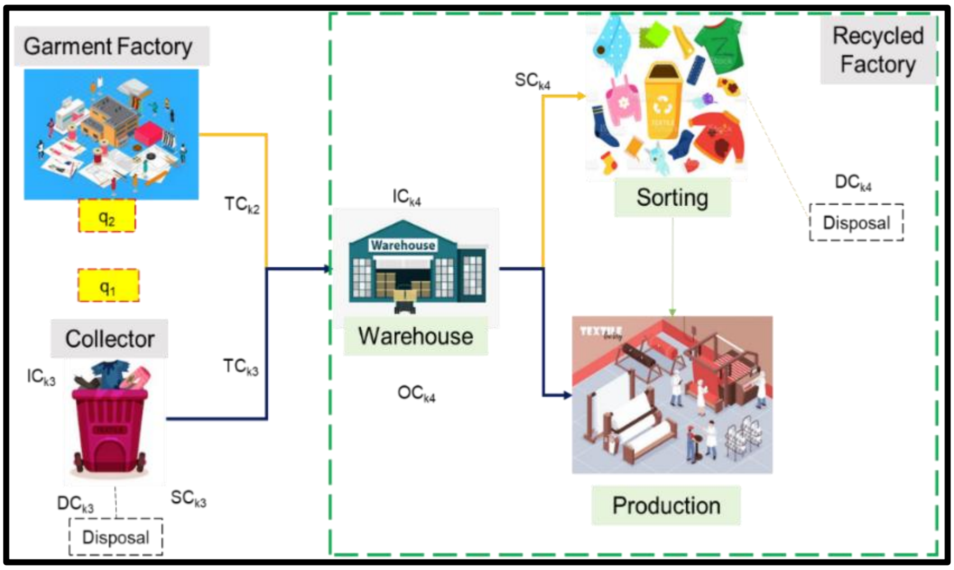

Fig. 1. Description of research problems

Notation:

TC = Transportation Cost
DC = Disposal Cost
IC = Inventory Cost
OC = Ordering Cost
SC = Sorting Cost
q = Production Lot size at Vendor
k2 = Garment Factory
k3 = Collector
k4 = Recycled Factory

3. RESEARCH METHOD

The research method of this study uses quantitative data, which are collected from PT. Superbtex Nonwoven Division using research instruments in the form of data recording tables and literature techniques from books and journals of previous researchers related to the multi-vendor single-buyer inventory system analysis. The objective of this research is to minimize total system cost of the company by using the model development based on the reference model by Kumar et al., 2017, with the addition of the waste sorting process, independent transportation costs (fixed and variable costs) from each vendor, and disposal costs for non-recyclable waste incurred by both the vendor and the buyer. The verification of the research model will be conducted using Excel, while the search for solutions will be performed using LINGO 18.0 software, which will assist the author in solving the research problem.

4. RESULT AND DISCUSSION

The sorting process conducted by the collector (vendor 1) leads to the creation of inventory at vendor 1. To avoid shortages of materials, the collector needs to store the sorted waste until it meets the buyer's production needs. On the other hand, the garment industry as vendor 2 does not consider inventory costs because waste is always available and can be directly sent to the buyer without any additional processes. Therefore, inventory costs are incurred only by vendor 1 and the buyer.

Fig. 2 illustrates the inventory dynamics at vendor 1 and the buyer in the current study. At time t_0, the buyer places an order for a lot size (Q) from the two vendors, q_1 and q_2. Simultaneously, vendor 1 starts the sorting process and divides it into two batches. Batch 1 is completed at time t_1, while batch 2 is completed at time t_3. However, if vendor 1 sends the sorted waste at time t_1 to the buyer, assuming that the demand rate at the buyer is greater than the production rate at vendor 1 ($D > P_1$), the buyer will finish producing batch 1 at time t_2 and have to wait for batch 2 to arrive at time t_3. This results in a shortage of materials at the buyer from t_2 to t_3. In other words, if vendor 1 sends batch 1 at time t_1, the quantity of materials will not be sufficient to meet the demand until batch 2 is sent at time t_3.

To avoid shortages at the buyer, it is assumed that when batch 1 is completed, the materials are not immediately sent to the buyer. Instead, vendor 1 stores batch 1 in inventory until the quantity is sufficient to meet the buyer's needs, ensuring uninterrupted material supply if the batches are sent sequentially. Thus, the figure explains that batch 1 is stored from time t_0 to t_2', and it will be sent to the buyer with a quantity of b, where b = a (quantity of batch 1), and batch 2 is sent from t_2' to t_3 as the remaining delivery.

In contrast, when the garment factory (vendor 2) receives an order from the buyer, vendor 2 can directly send the materials according to the order without any waiting time because vendor 2 does not undergo the additional sorting process like vendor 1 (as seen by the blue line in the buyer's inventory in Fig. 2), and the materials are processed immediately by the buyer upon arrival.

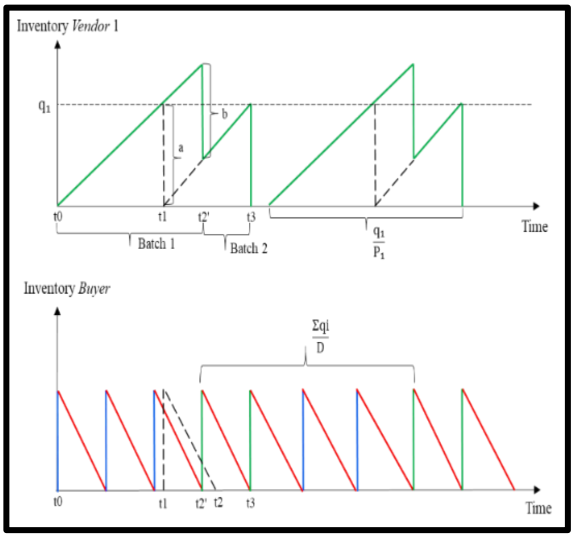

Fig. 2. Inventory dynamics of vendor 1 and buyer

Notations:

q_i = production lot size vendor i

a = the number of lots in batch 1 that should have been delivered at the time t_1

b = number of lots in batch 1 shipped

t_0 = the initial production time for the buyer uses materials from vendor 2 and the production process time for vendor 1

t_1 = batch 1 delivery time to the buyer that should be done

t_2 = the time when the production of batch 1 to the buyer is finished if vendor 1 sends batch 1 to t_1
t_2' = batch 1 delivery time to the buyer
t_3 = batch 2 delivery time to the buyer
P_1 = production rate at vendor
D = demand rate at buyer

= Goods come from vendor 1
= Goods come from vendor 2
= Goods are produced by the buyer

The following are the notations and units in the research:

Table 2. Definition of notations

Category	Notation	Definition
Parameter	k	Collector vendor -i (i = 1, …, n) and garment factory vendor -j (j = 1, …, n)
	q_k	Production quantity at vendor, $q_k = \beta_k . Q$ (unit/order)
	D	demand rate at buyer (unit/year)
	X	Truck capacity for transportation (kg/order)
	P_i	production rate at collector vendor -i (i = 1, …, n), (unit/year)
	F_x	fixed transportation cost for truck delivery (IRD/order)
	F_y	variable transportation cost per distance unit per weight unit (IRD/(kg.km))
	w_k	Unit weight at vendor (kg/unit)
	d_{k0}	distance from vendor to buyer (km)
	S_i	Waste sorting cost at collector vendor -i (i = 1, …, n), (IRD/kg)
	S_b	Waste sorting cost at buyer (IRD/kg)
	v_k	the percentage of waste generated by vendors (%)
	Ds_i	Disposal costs of waste produced by collector vendors -i (i = 1, …, n), (IRD/kg)
	Ds_b	Disposal costs (disposal) of waste produced by buyer (IRD/kg)
	$h_i^{(v)}$	unit inventory storage cost per unit time at the collector vendor (i = 1, …, n), (IRD/(unit.year))
	$h_{(b)}$	unit inventory storage cost per unit time at buyer (IRD/(unit.year))
	A	order fee to buyer for each message (IRD/order)
	T	Cycle time , T = Q/D
Variabel	$TC_{(v)}$	transportation cost vendor (IRD/year)
	$IC_{(v)}$	inventory cost vendor (IRD/year)
	$SC_{(v)}$	sorting cost vendor (IRD/ year)
	$DC_{(v)}$	disposal cost vendor (IRD/ year)
	$IC_{(b)}$	inventory cost buyer (IRD/ year)
	OC	ordering cost buyer (IRD/ year)
	$SC_{(b)}$	sorting cost buyer (IRD/ year)
	$DC_{(b)}$	disposal cost buyer (IRD/ year)
Decision Variable	β_k	proportion order lot size produced by each vendor
	Q	order lot size (unit/order)
	m_k	the frequency of sending batches per lot from vendor i to the buyer

The objective function of this research is to minimize the total system **cost** incurred by both the vendor and the buyer, taking into account transportation costs for each vendor, waste sorting costs prior to production, inventory costs for both the collecting vendor and the buyer, and the cost of disposing of non-recyclable waste. The following are the costs required by the vendor and the buyer based on the influence diagram in Figure 4 to determine the optimal values of Q, m_1, m_2, β_1, and to achieve the minimum total system cost.

Table 3. Development of pesearch mathematical models

	Total Cost Vendor	Total Cost Buyer
Transportation Cost	$\frac{D}{Q}\ (F_x + F_y . Q . \beta_k . w_k . d_{k0})$	
Inventory Cost	$\beta_i^2 . Q . D . h_i^{(v)} . (\frac{1}{2Pi} - \frac{(mi-2)}{2mi . D})$	$\sum \frac{Q(\beta k)^{2} . h^{(b)}}{2mk}$
Order Cost		$\frac{A.D}{Q}$
Sorting Cost	$\beta_i . (1+v_i) . S_i . w_i .D$	$\beta_j . (1+v_j) . S_b . w_j . D$
Disposal Cost	$\beta_{i.} v_i . Ds_i . w_i . D$	$\beta_j . v_j . Ds_b . w_j . D$

Based on the development of the research mathematical model in Table 3, the objective function of the research and its limitations are obtained, namely:

1. Research Objective Function is Minimum Total System Cost:

$$\text{Min T.C}_{(s)} = TC_{(v)k} + IC_{(v)i} + SC_{(v)i} + DC_{(v)i} + IC_{(b)} + OC + SC_{(b)} + DC_{(b)}$$

$$\text{Min T.C}_{(s)}\ (Q, \beta_i, \beta_j. m_i, m_j)$$

$$= \frac{D}{Q}\ (F_x + F_y\ .\ Q\ .\ \beta_k\ .\ w_k\ .\ d_{k0}) + \beta_i^2.\ Q\ .\ D\ .\ h_i^{(v)}.\ (\frac{1}{2Pi} - \frac{(mi-2)}{2mi\ .\ D}) + \beta_i\ .\ (1+ v_i)\ .\ S_i\ .\ w_i\ .D + \beta_{i\ .}\ v_i.\ Ds_i\ .\ w_i\ .\ D + \sum \frac{Q(\beta k)^2 \cdot h^{(b)}}{2mk} + \frac{A.D}{Q} + \beta_j\ .\ (1+ v_j)\ .\ S_b\ .\ w_j\ .D + \beta_j\ .\ v_j\ .\ Ds_b\ .\ w_j\ .\ D \quad (1)$$

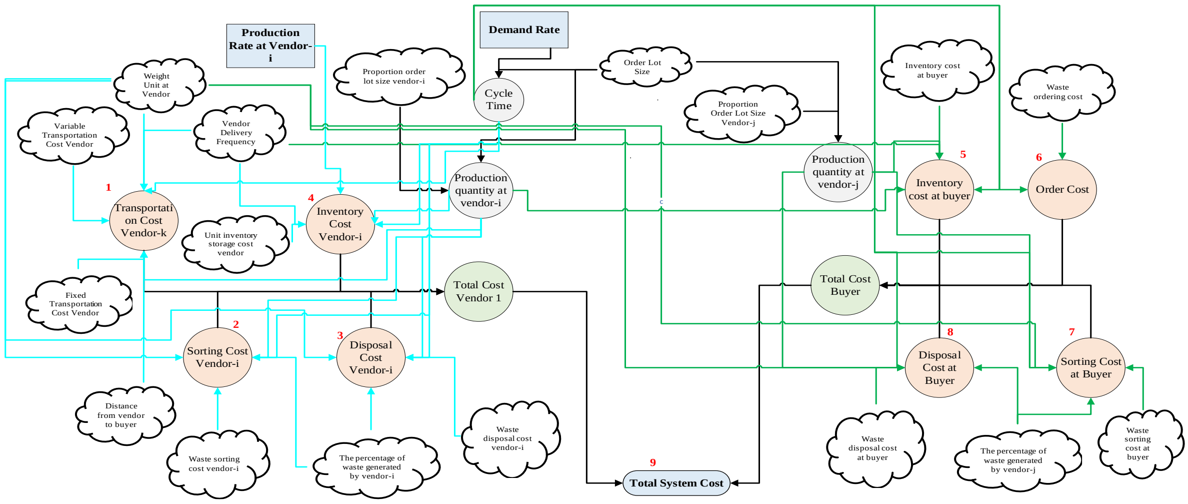

Fig. 3. Influence diagram of research

2. Research Limitation

- $\Sigma\beta_k = 1$ (2)
- $\beta_k\ .\ Q = q_k$ (3)
- $\frac{\beta k.\ Q\ .\ wk}{mk} \leq X$ (4)
- $\frac{\beta k.\ Q\ .\ wk}{X} > m_k$ (5)
- $q_i > 0$ (6)
- $Q > 0,\ Q \in R$ (7)
- $0 < \beta_k < 1$ (8)
- $\frac{\beta i\ .\ Q}{Pi} < \frac{\Sigma(\beta_k\ .\ Q)}{D}$ (9)
- $m_k > 0,\ m_k \in R$ (10)

Table 4 below is the research data used to achieve the desired research objectives by using 2 vendors, namely the i-th collector vendor (i = 1) and the j-th garment factory vendor (j = 2) to determine the optimal value of the decision variable Q*, β_1*, β_2*, m_1*, and m_2* and produce minimum total system cost. The research data in Table 4 tested came from PT. Superbtex Nonwoven Division and journal references.

Table 4. Research data

No.	Parameter	Value	Unit
1	F_x (transportation fixed cost)	5000	IRD/order
2	F_y (transportation variable cost)	25	IRD/(kg.km)
3	w_1 (weight unit at vendor 1)	3	kg/unit
4	w_2 (weight unit at vendor 2)	3	kg/unit
5	d_{10} (distance from vendor 1 to buyer)	10	km
6	d_{20} (distance from vendor 2 to buyer)	15	km
7	h_1 (unit inventory holding cost per unit time at vendor 1)	150	IRD/(unit.year)
8	h_b (unit inventory holding cost per unit time at buyer)	200	IRD/(unit.year)
9	P_1 (production rate at vendor 1)	4000	unit/year
10	D (demand rate at buyer)	6000	unit/year
11	v_1 (percentage of waste generated by vendors 1)	0,05	%
12	v_2 (percentage of waste generated by vendors 2)	0,05	%
13	A (ordering cost to the buyer per order)	5000	IRD/order
14	S_1 (waste sorting cost at vendor 1)	500	IRD/kg
15	S_b (waste sorting cost at buyer)	500	IRD/kg
16	Ds_1 (waste disposal cost of vendor 1's production waste)	500	IRD/kg
17	Ds_b (waste disposal cost of buyer's production waste)	500	IRD/kg
18	X (Truck capacity for transportation)	1000	kg/order

Based on the research data and the mathematical model in equation (11) along with the research constraints, the optimal values of decision variables and the minimum value of the objective function (total system cost) are obtained using LINGO 18.0 software, yielding the following global optimum results.

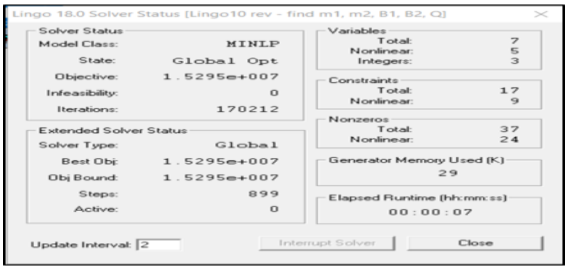

Fig. 4. Minimum total system cost value with LINGO 18.0 – global optima

Based on Fig. 4, the total minimum system cost is obtained, which is IRD. 15,295,000.-. With the class model, namely mixed integer nonlinear programming (MINLP), it produces a value with global optima status and 170212 iterations. The mixed integer nonlinear programming (MINLP) model is a form of mathematical programming with continuous, discrete, and nonlinear variables (variables that have powers greater than 1) with the objective function as well as the constraints that are generally used for optimization. In MINLP, at least one of the expressions in the model is nonlinear, and a subset of variables has integer constraints.

Row	Slack or Surplus	Dual Price
1	0.1529500E+08	-1.000000
2	0.000000	-0.1528333E+08
3	0.000000	0.000000
4	0.000000	0.000000
5	0.000000	0.000000
6	0.000000	0.000000
7	0.000000	-13888.89
8	0.000000	-5555.556
9	1333.333	0.000000
10	2000.000	0.000000
11	0.6666667	0.000000
12	0.3333333	0.000000
13	0.3333333	0.000000
14	0.6666667	0.000000
15	0.000000	4200000.
16	4.000000	0.000000
17	2.000000	0.000000

Variable	Value	Reduced Cost
FX	5000.000	0.000000
FY	25.00000	0.000000
W1	3.000000	0.000000
W2	3.000000	0.000000
D1	10.00000	0.000000
D2	15.00000	0.000000
H1	150.0000	0.000000
HB	200.0000	0.000000
P1	4000.000	0.000000
D	6000.000	0.000000
V1	0.5000000E-01	0.000000
V2	0.5000000E-01	0.000000
A	5000.000	0.000000
S1	500.0000	0.000000
SB	500.0000	0.000000
DS1	500.0000	0.000000
DSB	500.0000	0.000000
X	1000.000	0.000000
Q	2000.000	-5.833333
B1	0.6666667	0.000000
B2	0.3333333	0.000000
M1	4.000000	0.000000
M2	2.000000	0.000000
Q1	1333.333	0.000000
Q2	666.6667	0.000000

Fig. 5. Solution report model by LINGO 18.0

Based of Fig. 5, the optimum decision variable value of Q* is 2000 unit/ order; value of β_1* is 0,667; value of β_2* is 0,333; value of m_1* is 4, and value of m_2* is 2.

The result of this paper is presented in Table 5 by using 2 vendors. This explains that the optimal value of proportion order lot size produced by vendor 1 is 0,667 and vendor 2 is 0,333; the frequency of sending batches per lot from vendor 1 to the buyer is 4 times and for vendor 2 to the buyer is 2 times; and the optimum value of order lot size is 2000 unit/order so that the total minimum system cost for the company is IDR. 15.295.000/year

Table 5. Results of testing the research model with LINGO 18.0

Decision Variable	Optimal Value	Minimum Total System Cost (IRD/year)
Q* (unit/order)	2000	
β_1*	0,667	
β_2*	0,333	15.295.000
m_1*	4	
m_2*	2	

And in Fig. 6 is the inventory dynamics at vendor 1 and buyer based on the research results that have been obtained in Table 5.

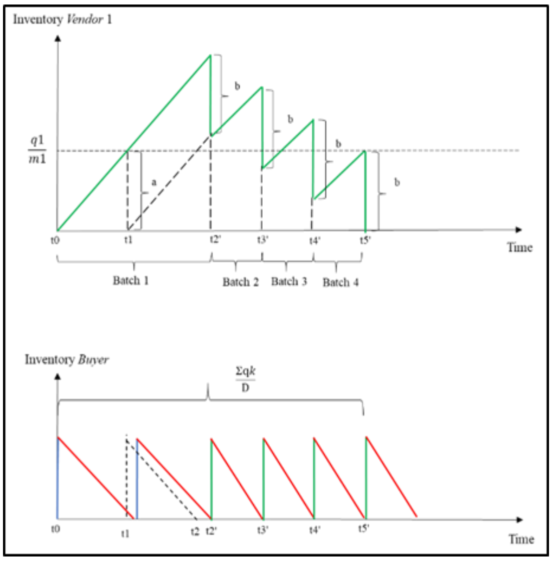

Fig. 6. The inventory dynamics of research results in vendor 1 and buyer

Notations:

q_i = production lot size vendor -i

a = the number of lots in batch 1 that should have been shipped at t_1

b = the number of lots in each batch shipped

t_0 = the initial production time for the buyer using materials from vendor 2 and the production processing time for vendor 1 as well as the time for ordering from vendors

t_1 = batch 1 delivery time to the buyer that should be done

t_2 = the time when production of batch 1 at buyer is finished if vendor 1 sends batch 1 at t_1

t_2'; t_3'; t_4'; t_5' = delivery time batch 1, 2, 3, 4 to the buyer

D = demand rate at buyer

= Goods come from vendor 1
= Goods come from vendor 2
= Goods produced at buyer

4.1 Sensitivity Analysis Result

The following is the result of sensitivity analysis on changes in 3 parameters in the study, namely demand rate, vendor 1 production rate, and delivery truck capacity.

Table 6. Sensitivity Analysis Results to Parameter Changes

Parameter	% Chg	Q* (% Chg)	β_1* (% Chg)	β_2* (% Chg)	m_1* (% Chg)	m_2* (% Chg)	TC (% Chg)
Demand Rate (D)	+10	150,00	-10,04	20,12	125,00	200,00	11,15
	+20	50,00	-16,64	33,33	125,00	100,00	21,82
	+30	0,00	-25,04	50,15	125,00	50,00	32,95
	-10	150,00	9,90	-19,82	175,00	100,00	-10,71
	-20	0,00	24,89	-49,85	25,00	-50,00	-21,86
	-30	100,00	37,48	-75,08	175,00	-50,00	-32,54
Production Rate Vendor 1 (P_1)	+15	100,00	12,44	-24,92	125,00	50,00	100,00
	+25	100,00	24,89	-49,85	125,00	0,00	100,00
	+35	50,00	33,28	100,00	125,00	-50,00	50,00
	-15	50,00	-16,64	33,33	25,00	100,00	1,63
	-25	0,00	-25,04	50,15	-25,00	50,00	2,42
	-35	100,00	-37,48	75,08	25,00	250,00	3,68
Truck Capacity (X)	+10	10,00	10,00	0,00	0,00	0,00	0,00
	+30	20,00	20,00	0,00	0,00	0,00	0,00
	+50	50,00	50,00	0,00	0,00	0,00	0,00
	-10	-10,00	35,00	0,00	0,00	50,00	50,00
	-30	-20,00	20,00	0,00	0,00	50,00	50,00
	-50	-50,00	25,00	0,00	0,00	150,00	150,00

Notation:
% Chg = Persentation Change

The yellow color in Table 6 shows the highest percentage change value of the decision variable to parameter changes. In the decision variable order lot size (Q), the largest change in value experienced is 150% when there is a change in the demand rate (D) parameter which increases by 10% and decreases by 10%. In the decision variable proportion order lot size vendor 1 (β_1), the largest change in value is 50% when there is a change in the truck capacity parameter (X) which increases by 50%. In the decision variable the proportion of order lot size vendor 2 (β_2), the largest change in value is 100% when there is a change in the vendor 1 production rate parameter which increases by 35%. In the vendor delivery frequency decision variable 1 (m_1), the biggest change in value is 175% when the demand rate (D) decreases by 10% and 30%. In the decision variable vendor delivery frequency 2 (m_2), the largest change in value is 250% when there is a change in vendor 1's production rate parameter (P_1), which decreases by 35%. Meanwhile, the biggest change experienced by the total system cost (T.C) is 150% when there is a 50% reduction in the value of truck capacity (X). Meanwhile, changes in the cost parameter to the total system cost are shown in Table 7.

Table 7. Results of sensitivity analysis of changes in cost parameters to total system costs

Parameter	% Change	Q* (% Change)	TC (% Change)	Information
Transportation Fixed Cost (Fx)	+25	0.00	0.04	The total system cost (TC) value is slightly sensitive to changes in transportation fixed costs (Fx)
	+50	0.00	0.08	
	-25	50.00	-0.05	
	-50	50.00	-0.10	
Transportation Variable Cost (Fy)	+25	0.00	8.58	The value of the total system cost (TC) is sensitive to changes in the variable cost of transportation (Fy)
	+50	0.00	17.16	
	-25	0.00	-8.58	
	-50	0.00	-17.16	
Vendor 1 Inventory Cost (h1)	+25	50.00	0.11	The total system cost (TC) value is somewhat sensitive to changes in vendor 1 inventory costs (h1)
	+50	50.00	0.22	
	-25	0.00	-0.13	
	-50	0.00	-0.26	
Buyer Inventory Cost (hb)	+25	0.00	0.05	The value of total system cost (TC) is
	+50	0.00	0.11	

Parameter	% Change	Q* (% Change)	TC (% Change)	Information
	-25	0.00	-0.05	somewhat sensitive to changes in buyer inventory cost (hb)
	-50	0.00	-0.11	
Vendor 1 Sorting Cost (S1)	+25	0.00	9.18	The total system cost (TC) value is sensitive to changes in vendor 1 sorting cost (S1)
	+50	0.00	10.10	
	-25	200.00	-10.30	
	-50	200.00	-20.59	
Buyer Sorting Cost (Sb)	+25	200.00	5.15	The value of total system cost (TC) is sensitive to changes in buyer sorting costs (Sb)
	+50	200.00	10.30	
	-25	0.00	-6.21	
	-50	0.00	-21.72	
Vendor 1 Disposal Cost (Ds1)	+25	0.00	0.49	The total system cost (TC) value is somewhat sensitive to changes in vendor 1 disposal costs (Ds1)
	+50	0.00	0.98	
	-25	0.00	-0.49	
	-50	0.00	-0.98	
Buyer Disposal Cost (Dsb)	+25	0.00	0.25	The value of total system cost (TC) is somewhat sensitive to changes in buyer disposal costs (Dsb)
	+50	0.00	0.49	
	-25	0.00	-0.25	
	-50	0.00	-0.49	
Ordering Cost (A)	+25	0.00	0.02	The value of the total system cost (TC) is slightly sensitive to changes in the cost of ordering (A)
	+50	0.00	0.04	
	-25	0.00	-0.02	
	-50	50.00	-0.05	

Based on Table 7 it can be seen that the value of the total system cost (T.C) is sensitive to changes in the parameters of variable transportation costs (Fy), vendor 1 sorting costs (S_1), and buyer sorting costs (Sb). This shows that the three costs (Fy, S_1, and Sb) must be estimated carefully to determine the optimal system cost.

5. CONCLUSION

Based on the tests that have been carried out, it can be proven that the model in this study can determine the optimal value of the five decision variables and minimize the total system cost. The model below of the integrated multi-vendor single-buyer inventory system that has been developed can also be used for cases of selecting 2 or more vendors.

$$\text{Min } T.C_{(s)} = TC_{(v)k} + IC_{(v)i} + SC_{(v)i} + DC_{(v)i} + IC_{(b)} + OC + SC_{(b)} + DC_{(b)}$$

$$\text{Min } T.C_{(s)} (Q, \beta_i, \beta_j. m_i, m_j) = \frac{D}{Q} (F_x + F_y . Q . \beta_k . w_k . d_{k0}) + \beta_i^2. Q . D . h_i^{(v)}. \left(\frac{1}{2Pi} - \frac{(mi-2)}{2mi . D}\right) + \beta_i . (1+ v_i) . S_i . w_i .D + \beta_i . v_i. Ds_i . w_i . D + \sum \frac{Q(\beta k)^2 \cdot h^{(b)}}{2mk} + \frac{A.D}{Q} + \beta_j . (1+ v_j) . S_b . w_j . D + \beta_j . v_j . Ds_b . w_j . D$$

This model of EOQ (Economic Order Quantity) aims to minimize the total system cost incurred by both the vendor and the buyer, taking into account transportation costs for each vendor, waste sorting costs prior to production, inventory costs for both the collecting vendor and the buyer, the cost of disposing of non-recyclable waste and to determine the optimal values of Q, m_1, m_2, β_1, and β_2 to achieve the minimum total system cost. Behavioral analysis for parameter changes has been carried out and it can be concluded that vendor 1 (S1) sorting costs, buyer (Sb) sorting costs, transportation variable costs (Fy), delivery truck capacities (X), and demand rates (D) have a significant effect significantly to changes in total system cost (TC). So that the five parameters need to be estimated carefully to determine the optimal system cost. The current research only uses deterministic demand where in real conditions, most companies have varying or changing demands, so this research can be developed by considering probabilistic demand and multi item-multi buyer.

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