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Multi objective optimization approach for multi-item inventory control: A case study in leather industry

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ABSTRACT
PT ASA is a leather tanning company. Almost 65% of the company's assets are allocated for the procurement of raw leather, which consists of goat and sheepskin. In addition to being expensive, the availability of raw leather is also very limited. The company faces a trade-off where, on one hand, the raw material is easily decayed, but on the other hand, its availability is extremely limited, and if there is not enough inventory, the production process will be disrupted. In this research, a multi-objective optimization model is developed for controlling the inventory of raw leather using the Fuzzy Goal Programming approach. The objectives to be achieved are to minimize the total inventory cost, maximize the total quantity of raw leather that meets standards, and minimize the total cost of losses due to decayed raw leather. Based on the calculations, the fuzzy goal programming membership function value is obtained at 0.9155, with a total inventory cost over the planning horizon of IDR 10,341,630,000, a total of 1,279,542 sq ft of raw leather meeting standards, and a total loss cost due to decayed raw leather of IDR 142,911,691.

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1. INTRODUCTION

The availability of raw materials is one of the factors that affect the smoothness of production process activities. Without raw materials, companies face the risk of being unable to meet the needs and market demand if demand suddenly increases [1]. However, on the other hand, inventory also requires special handling, not only because it requires a significant capital investment for procurement, but also because the risk of quality deterioration and damage to stored goods must be to be considered [2]. Therefore, proper inventory control is necessary to maximize the company's profits.

PT ASA's leather division is an industry engaged in leather tanning, which processes raw leather into ready-to-use leather sheets. The raw materials used are raw goat and sheep leather obtained from several suppliers. Production of ready-to-use leather sheets can reach 120,000 sheets per month with various categories. The investment value for the management of raw leather raw material inventory by the company is quite significant, accounts for almost 65% of the total assets owned by the company.

The company always strives to maintain consumer trust by consistently meeting market demand. Therefore, the availability of raw leather raw materials is ensured to prevent production disruptions. However, due to the uncertain supply of raw leather from suppliers, both in terms of timing and quantity, the company often purchases raw leather from multiple suppliers without considering the required quantity, resulting in frequent overstock of raw leather in the warehouse. On the other hand, raw leather raw materials have a shelf life, and the longer they are stored, the more likely there will be a decrease in quality or even spoilage.

Based on observations, it is known that, on average, raw leather materials begin to deteriorate at a rate of around a dozen stacks per week. Each stack consists of 30 bundles, and each bundle contains 10-15 sheets of raw leather. However, raw materials experiencing decay cannot be processed directly into products but must go through repeated tanning and coloring processes (rework) to make the resulting products still saleable, albeit at a lower price. Consequently, the losses incurred by the company due to spoiled leather sheets include losses resulting from rework activities and losses due to lower selling prices.. If this issue continues unchecked, it is feared that company's losses will increase. Hence, a solution needs to be found regarding the optimal raw material inventory control policy at PT ASA to minimize possible cost and loss risks while maintaining the availability of raw leather to meet customer demand.

The objective of this research is to develop a multi-objective optimization model for raw leather inventory control at PT ASA, with the objectives of minimizing the total inventory cost, maximizing the quantity of raw leather that meets standards, and minimizing the total cost of losses due to spoiled inventory. The expected benefit of this research is to generate an optimal raw leather inventory control policy to avoid overstocking, ultimately minimizing the company's losses while still meeting consumer demand.

The mathematical model is important to translate real-world problem to find the solution. However, ranslating real-world problem into a mathematical model becomes more complicated when uncertainties are contained in the system. Decision maker faced with environments in which both fuzziness and randomness are included causes the developed mathematical model should carefully treat these uncertainties [3]. Decision-making involving multiple objectives requires a linear program with a single objective function to solve simultaneously. Therefore, in this research, multi-objective linear programming with Fuzzy Goal Programming is used. Fuzzy elements are used to handle inaccuracies in expressing the desired objective functions.

2. MATERIALS AND METHODS

Linear programming (LP) is used to optimize an objective function subject to certain constraint functions. In real-life situations, companies often face decision-making involving multiple objective functions, making it impossible to use linear programming for decision-making. Instead, a more relevant approach is required [4]. Multi-objective optimization is a natural extension of the traditional optimization of a single-objective function. If the multi-objective functions are commensurate, or non-competing minimizing one-objective function minimizes all criteria and using traditional optimization techniques can solve the problem [5].

Multi-objective programming involves recognition that the decision maker is responding to multiple objectives. Generally, objectives are conflicting, so not all objectives can simultaneously arrive at their optimal levels. Multiple objectives can involve such considerations as leisure, decreasing marginal utility of income, risk avoidance, preferences for hired labor, and satisfaction of desirable, but not obligatory, constraints [6, 7]. The objective in a multi-objective optimization is different from that in a single-objective optimization [8, 9]. In multi-objective optimization the goal is to find as many different Pareto-optimal (or near Pareto-optimal) solutions as possible [10]. Since classical optimization methods work with a single solution in each iteration, in order to find multiple Pareto-optimal solutions they are required to be applied more than once, hopefully finding one distinct Pareto-optimal solution each time [11].

Goal programming (GP) is a branch of multi objective of optimization, which in turn is a branch of multi-objective decision making (MODM) also known as multi-criteria decision making (MCDM). GP models consist of three components: an objective function, a set of goal constraints, and non-negativity requirements. It can be thought of as an extension or generalization of linear programming to handle multiple, normally conflicting objective measures. Each of these measures is given a goal or target value to be achieved Deviations are measured from these goals both above and below the target. Unwanted deviations from this set of target values are then minimized in an achievement function. This can be a vector or a weighted sum a dependent on the goal programming variant used [12].

In a real situation for optimization problems, many input information are not known precisely [13, 14]. Traditional mathematical programming techniques clearly cannot solve all fuzzy programming problems. However, the target value associated with each goal could be fuzzy in the real-world application. The method that uses fuzzy sets in GP is called Fuzzy Goal Programming (FGP). FGP is an extension of conventional goal programming to solve multi-objective problems with imprecisely defined model parameters in a decision-making environment [15]. It is an extension of conventional goal programming to solve multi-objective problems with fuzzily described model parameters [3, 6, 16, 17, 18, 19].

The fuzzy set theory was proposed by Zadeh [20] and has been found extensive in recent research. Many contributions to fuzzy sets theory/applications appeared after Zadeh proposed fuzzy sets as a branch of mathematics for uncertainty analysis. One of the most influential works in uncertain decision making was later written by Bellman and Zadeh [21] who gave the foundations of decision making and optimization models in a fuzzy environment and opened the door to involve fuzzy sets into optimization models/methods. Various types of membership functions can be used to support the fuzzy analytical framework although the fuzzy description is hypothetical and membership values are subjective [22].

FGP can be formulated [4, 23, 24], as follows:

If defined as $x = [x_1, x_2, \dots, x_n]^T \in R^n$ as the vector of decision variables and $f(x) = \{f_1(x), f_2(x), \dots, f_m(x)\}$ are the objective functions with constraint system, $G(x)$.

Decision-makers want constraints $f_i^*, (i = 1,2, \dots, m)$ for each objective function that satisfy linear constraints $G(x)$. Using a fuzzy set, membership functions can be defined based on the following steps:

1. Express:

$$Max\ f_i(x), i = 1,2, \dots, m \tag{1}$$

   Subject to $x \in G(x) \in R^n$

   Let $x_j^*, (j = 1,2, \dots, n)$ is the optimal solution for objective function $f_i(x)$, take $f_i(x_j^*) = f_{i\,max}$

2. Determine Min $f_i(x_j^*) = f_{i\,min}$ for each i
3. Define the fuzzy membership function [4], [12], [25] $\mu_{f_i(x)}, (i = 1,2, \dots, m)$ in the form of

$$\mu_{f_i}(x) = \begin{cases} \dfrac{f_{i\,max} - f_i(x)}{f_{i\,max} - f_i^*}, & f_i^* < f_i(x) \le f_{i\,max} \\ 1 & f_i(x) = f_i^* \\ \dfrac{f_i(x) - f_{i\,min}}{f_i^* - f_{i\,min}}, & f_{i\,min} \le f_i(x) < f_i^* \end{cases} \tag{2}$$

Define a set $F(\lambda, x)$, forming the FGP model, by determining x^* that satisfies:

$$Max\ \lambda \tag{3}$$

Subject to $x \in F(\lambda, x) \cap G(x)$

where $F(\lambda, x) = F^\lambda(x) = F_1^\lambda \cap \dots \cap F_i^\lambda \dots \cap F_m^\lambda$

with $F_1^\lambda(x) = \{x | \mu_{f_i(x)} \ge \lambda; 0 \le \lambda \le 1; x \in F_i(x)\}$

Because the objective function in the model to be discussed is a maximization and minimization problem, according to Singh et al. (2011) FGP can be expressed as

$$\text{Determine } x \text{ such that } F_i(x) \le f_i \text{ atau } F_i(x) \ge f_i \tag{4}$$

Subject to $Ax \le b, x \ge 0$

where

$F_i(x)$: the objective function i

f_i : the aspiration level of the objective function $F_i(x)$

A : coefficient matrix to generate a decision variable value x_j

b : column vector on the right-hand side of the constraint

The membership function $\mu_{f_i}(x)$ for each fuzzy objective can be expressed in the following

- If $F_i(x) \le f_i$

$$\mu_{f_i}(x) = \begin{cases} 1\ , & F_i(x) \le f_i \\ \dfrac{U_i - F_i(x)}{U_i - f_i}\ , & f_i \le F_i(x) \le U_i \\ 0\ , & F_i(x) \ge U_i \end{cases} \tag{5}$$

- If $F_i(x) \ge f_i$

$$\mu_{f_i}(x) = \begin{cases} 1\ , & F_i(x) \ge f_i \\ \dfrac{F_i(x) - L_i}{f_i - L_i}\ , & L_i \le F_i(x) \le f_i \\ 0\ , & F_i(x) \le L_i \end{cases} \tag{6}$$

Where U_i and L_i is the upper and lower bounds of decision maker preferences. And f_i is the desired optimal constraint (max/min) of the model.
FGP model (3) and (4) can be expressed in the form
Determine x^* that satisfies

$$Max\ \lambda \tag{7}$$

subject to
$\mu_{f_i(x)} \ge \lambda$
$Ax \le b, x \ge 0$

The fuzziness of each objective function is

$$\mu_{f_i}(x) = \begin{cases} 1\ , & F_i(x) \le f_{i\,min} \\ \dfrac{U_i - F_i(x)}{U_i - f_{i\,min}}\ , & f_{i\,min} \le F_i(x) \le U_i \\ 0\ , & F_i(x) \ge U_i \end{cases} \tag{8}$$

$$\mu_{f_i}(x) = \begin{cases} 1\ , & F_i(x) \ge f_{i\,max} \\ \dfrac{F_i(x) - L_i}{f_{i\,max} - L_i}\ , & L_i \le F_i(x) \le f_{i\,max} \\ 0\ , & F_i(x) \le L_i \end{cases} \tag{9}$$

The form of the membership function in the equation (8) and (9) can be depicted at Figure 1

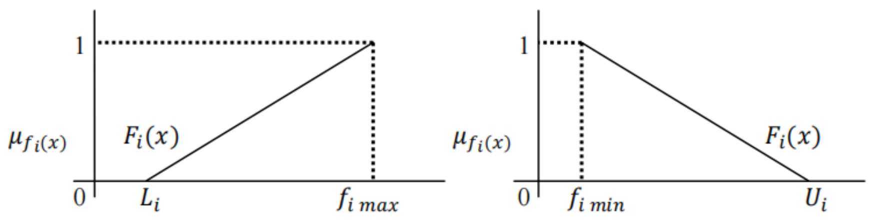

Figure 1 The general form of the fuzzy membership function of the objective function in the FGP model

3. RESULT

In this research, a multi-objective optimization model will be developed using the fuzzy goal programming approach to control the inventory of raw leather materials. The model's objectives are to minimize the total inventory cost, maximize the total quantity of raw leather materials that meet the standards, and minimize the total cost of losses due to spoiled inventory. The fuzzy goal programming model approach is based on the research by Prayogo [26] and Yu et al. [27]. The following are the stages in formulating the fuzzy goal programming model for controlling the inventory of raw leather materials based on the existing system characteristics at PT ASA.

3.1. Notation

The following are some notations used in the development of the proposed model
Index
i : type of raw material, $i = 1, 2, \ldots, i$

s	:	supplier, $s = 1, 2, \dots, s$
t	:	period, $t = 1, 2, \dots, t$

Decision variables

Q_{ist}	:	the quantity of raw material purchased for item i from supplier s in time period t
X_{ist}	:	purchase decision for raw material for item i from supplier s in time period t
I_{it}	:	inventory quantity of raw material for item i in time period t
Y_{st}	:	order decision to supplier s in time period t
Z_{ist}	:	purchase decision of raw material for item i from supplier s to meet the demand in time period t

Parameters

D_{it}	:	demand quantity of raw material for item i in time period t
C_{is}	:	supply capacity of raw material for item i from supplier s
P_{is}	:	price of raw material for item i from supplier s
q_{is}	:	quality of raw material for item i dari supplier s
mo_s	:	minimum order to supplier s
Cp_s	:	ordering cost to supplier s
Ck_s	:	shipping cost from supplier s
Ch_i	:	holding cost of raw material item i
Cr_i	:	rework cost due to decayed raw material i
R	:	quantity of decayed inventory (10% of I_{it})
M	:	a positive number with a very large value

3.2. Mathematical formulation

Objective Functions:

1. Minimize the total inventory cost over the planning horizon

$$Min\ f_1 = \sum_i \sum_s \sum_t P_{is} Q_{ist} + \sum_s \sum_t Ck_s Y_{st} + \sum_s \sum_t Cp_s Y_{st} + \sum_i \sum_t Ch_i I_{it} \tag{10}$$

2. Maximize the total quantity of raw materials meeting standards over the planning horizon

$$Max{:}\ f_2 = \sum_i \sum_s \sum_t q_{is} Q_{ist} \tag{11}$$

3. Minimize the cost of losses due to decayed inventory over the planning horizon

$$Min{:}\ f_3 = \sum_i \sum_t Cr_i . R \tag{12}$$

4. Objective functions of the Fuzzy Goal Programming Model

$$Max{:}\ \lambda \tag{13}$$

Constraint Functions:

1) The total quantity of raw material item i meeting standards received from all suppliers s in time period t plus the inventory of raw material i from the previous period, must satisfy the demand for raw material i in time period t.

$$\sum_s q_{is} Q_{ist} + I_{it-1} \geq D_{it}\ ; \quad \forall\ i, t \tag{14}$$

2) Inventory balance constraint for raw material i in time period t

$$I_{it} = I_{it-1} + \sum_s q_{is} Q_{ist} - D_{it}\ ; \ \forall\ i, t \tag{15}$$

3) The quantity of raw material i delivered from supplier s in time period t must not exceed the supply capacity of raw material i from supplier s

$$Q_{ist} \leq C_{is} \quad ; \qquad \forall\, i, s, t \tag{16}$$

4) The relationship between the purchase decision of raw material i from supplier s in time period t and the ordering decision to supplier s in time period t

$$\sum_i X_{ist} \leq M.Y_{st} \;; \qquad \forall\, s, t \tag{17}$$

5) The total quantity of deliveries of all types of raw material i from supplier s in time period t must meet the minimum order requirement from supplier s

$$\sum_i Q_{ist} \geq mo_s \;; \qquad \forall\, s, t \tag{18}$$

6) If the demand for raw material i pada periode t exceeds the inventory of raw material i in time period t then the purchase decision of raw material i from supplier s to meet the demand in time period t, Z_{ist} will have a value of 1 and 0 otherwise

$$(D_{it} - I_{it-1})X_{ist} \leq M.Z_{ist} \;; \quad \forall\, i, t \tag{19}$$

7) Binary decision variables are

$$X_{ist}, Z_{ist}, Y_{st} \in [1,0] \;; \quad \forall\, i, s, t \tag{20}$$

8) Non-negative constraints for the quantity of raw material i purchased from supplier s in time period t and the inventory of raw material i in time period t

$$Q_{ist}.I_{it} \geq 0 \;; \quad \forall\, i, s, t \tag{21}$$

9) Constraints for the objective function of Fuzzy Goal Integer Programming

a. $$\frac{f_1^{-} - f_1}{f_1^{-} - f_1^{+}} \geq \lambda \tag{22}$$

b. $$\frac{f_2 - f_2^{-}}{f_2^{+} - f_2^{-}} \geq \lambda \tag{23}$$

c. $$\frac{f_3^{-} - f_3}{f_3^{-} - f_3^{+}} \geq \lambda \tag{24}$$

3.3. Model solution

The steps in Fuzzy Goal Programming [24] are

1. Choose products that want to be optimized.
2. Entering input values for each product like product selling prices, costs of production, the minimum amount of production, and the maximum amount of production.
3. Input three levels of aspiration or goal function to be achieved.
4. Go to the first calculation phase, seeking optimal value for the third factor that is maximize profits, minimize costs of raw materials, and minimize production costs. If there is no an optimal solution to the first calculation phase then go back to step 2.
5. Comparing the three level 3 aspirations with the optimal value goal factors. If all three levels of aspiration meets the requirements then phase calculation using fuzzy goal programming can be done. If there is an aspiration level which does not meet the requirements then go back to step 3.
6. Establish a fuzzy goal programming calculation model.
7. Entry into the calculation phase fuzzy goal programming. fuzzy goal programming calculations model will yield a solution that will be displayed on the screen. when fuzzy goal programming model not produce a solution then go back to step 2.

4. DISCUSSION

Validation of this model will be carried out, namely by applying the model to real cases at the at PT ASA. So far, PT ASA has required two types of raw materials, which are goat leather and raw sheepskin, supplied by 4 suppliers with a planning horizon of 8 weeks. The data collected from PT ASA can be seen in Table 1 to Table 4.

Table 1 Raw material requirements (sqft)

Period	**Type of leather**	
	Leather-1	**Leather-2**
1	77.960	44.240
2	68.490	46.630
3	67.390	43.840
4	73.530	42.350
5	71.220	42.570
6	73.670	46.280
7	75.790	45.890
8	71.620	48.260

Leather 1 = Goat leather
Leather 2 = Sheep leather

Table 2 Supply capacity, proportion of standard raw materials, and purchase price

Supplier	**Supply Capacity (sqft)**		**Proportion of standard raw materials**		**Purchase price, (IDR/sqft)**	
	Leather-1	**Leather-2**	**Leather-1**	**Leather-2**	**Leather-1**	**Leather-2**
1	32.000	16.000	0.80	0.80	8.000	11.000
2	25.000	20.000	0.85	0.95	8.500	12.500
3	35.000	15.000	0.90	0.90	9.000	12.000
4	30.000	20.000	0.80	0.85	8.500	11.500

Table 3 Ordering cost, shipping cost, and minimum order

Supplier	**Ordering cost, (IDR/order)**	**Shipping cost, (IDR/ship)**	**Minimum order, (sqft)**
1	3.000.000	28.000	450.000
2	2.500.000	24.000	400.000
3	3.000.000	25.000	400.000
4	2.500.000	27.000	450.000

Table 4 Initial inventory, holding cost, and rework cost

Raw material	**Initial inventory (sqft)**	**Holding cost, (IDR/sqft/period)**	**Rework cost, (IDR/sqft)**
Leather-1	42.280	150	4.000
Leather-2	26.880	200	6.000

The procedure for solving the multi-objective optimization model is carried out by solving each objective function separately and then finding the fuzzy value, λ, using the negative and positive ideal solution values from each objective function. The large number of variables considered makes the calculation process more complex. Therefore, solving for the optimization values for each objective function is done with the assistance of Lingo software.

The results of searching for optimal solutions for the objective functions in eqs. (10-12) with constraint functions in eqs. (14)-(21) using Lingo software yielded the negative and positive ideal solution values for each objective function, as shown in Table 5. Next, we find the fuzzy value λ using fuzzy goal programming. The constraint functions are determined using fuzzy membership functions and adjusted for each objective function, namely objective functions f_1, f_2, and f_3 in order to maximize λ.

Table 5 Objective function at the optimal solution

Objective function	f_1	f_2	f_3
f_1	**9867325000**	*15481109500*	10036337650
f_2	872104	**1317200**	*871491*
f_3	63580560	*1079596000*	**56467570**

Note: Values in **bold** indicate the positive ideal solution, values in *italics* indicate the negative ideal solution.

The constraint functions for fuzzy goal programming in eqs. (22)-(24) for each objective function f_1, f_2, and f_3 can be simplified as follows

$$f_1 + 5.613.784.500\lambda \leq 15.481.109.500$$
$$f_2 - 445.709\lambda \geq 871.491$$
$$f_3 + 1.023.128.430\lambda \leq 1.079.596.000$$

Based on the solution obtained using Lingo software, the fuzzy value $\lambda = 0{,}9155$. Next, this λ value is substituted into the constraint functions of the fuzzy goal programming to obtain the optimal solution for all objective functions. The optimal results are as follows:

$f_1{}^* = 10{,}341{,}630{,}000$;
$f_2{}^* = 1{,}279{,}542$; and
$f_3{}^* = 142{,}911{,}691$

Therefore, based on the optimization results of the fuzzy goal programming model, the minimum total inventory cost during the planning horizon is IDR 10,341,630,000; the maximum total quantity of raw materials standards goat and sheep leather during the planning horizon is 1,279,542 sqft, with the proportion of goat leather at 62% and sheep leather at 38%. The minimum cost of losses due to damaged inventory during the planning horizon is IDR 142,911,691.

Sensitivity Analysis

Sensitivity analysis is conducted to determine the extent to which parameters affect a model. Sensitivity analysis will be performed using two methods: first, by altering the value of the raw material requirement parameter, D_{it}, for item i in time period t, and observing whether this change affects the quantity of raw material i from supplier s in time period t (Q_{ist}). The second method involves modifying the purchase price parameter, P_{is} of raw material i from supplier s and assessing whether this change has an impact on the total inventory cost over the planning horizon.

The first sensitivity analysis involves altering the value of the raw material requirement for item 1 in time period t (D_{it}), by decreasing it in all time periods t. The changes can be seen in Table 6.

Table 6 Changes in leather requirements (sqft)

Period	**Leather requirements**	
	Before	**After**
1	77,960	57,960
2	68,490	58,490
3	67,390	57,390
4	73,530	53,530

Table 6 Changes in leather requirements (sqft) (Continued)

Period	Leather requirements	
	Before	After
5	71,220	51,220
6	73,670	53,670
7	75,790	55,790
8	71,620	51,620s

The calculation results indicate that the total quantity of raw material i purchased from supplier s in time period t based on the initial requirements, is 634,191 sqft. However, the total quantity of raw material purchased from supplier s in time period t with the new requirements is 440,709 sqft. From these results, it can be observed that the quantity of raw material purchased from supplier s in time period t (Q_{ist}) and the raw material requirement in time period t (D_{it}) are directly proportional; when the requirement decreases, the purchase of raw material also decreases, and vice versa. The distribution of data per period for Q_{ist} with initial requirements and Q_{ist} with reduced requirements can be seen in Figure 2.

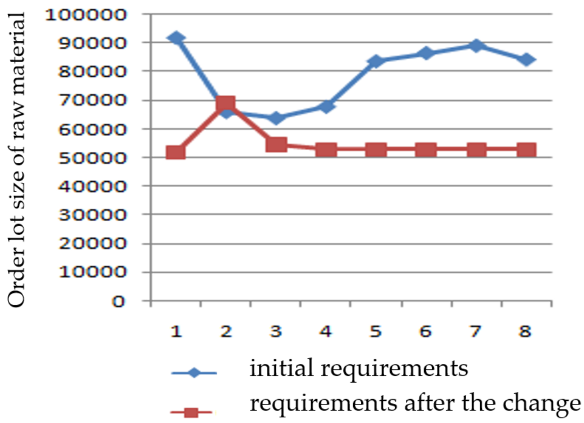

Figure 2 Sensitivity analysis of changes in requirements on purchase quantity

The second sensitivity analysis involves altering the purchase price parameter, P_{is}, of raw material i from supplier s and assessing whether this change affects the total inventory cost over the planning horizon. Changes in the purchase price parameter data for raw material i from supplier s (P_{is}) can be seen in Table 7.

Table 7 Changes in leather purchase prices P_{is} (IDR/sqft)

Supplier	Before		After	
	Leather-1	Leather-2	Leather-1	Leather-2
1	8,000	11,000	5,000	6,000
2	8,500	12,500	5,500	8,500
3	9,000	12,000	6,000	8,000
4	8,500	11,500	5,500	6,500

The calculation results for the total inventory cost over the planning horizon (f_1) using the initial price data are IDR 9,867,325,000, while the results for the total inventory cost over the planning horizon (f_1) using the new price data are IDR 6,160,271,000. From these results, it can be observed that as the purchase price of raw materials decreases, the total inventory cost over the planning horizon also decreases, and vice versa.

5. CONCLUSION

In this research, a multi-objective inventory control model for leather raw materials has been developed using the fuzzy goal programming approach. The considered multi-objectives for making optimal decisions include minimizing the total inventory cost over the planning horizon, maximizing the total quantity of high-quality raw materials meeting standards, and minimizing the cost of damaged raw materials. Based on the model validation conducted using empirical data from PT ASA, an optimal raw material procurement policy has been obtained, with a total inventory cost of IDR 10,341,630,000, a total quantity of high-quality raw materials of 1,279,542 sqft, and a total cost due to damaged raw materials of IDR 142,911,691.

The sensitivity analysis results indicate that parameter values will affect the determination of the order quantity based on the modeled inventory problem. Additionally, by altering parameter values, the model still provides optimal results, suggesting that the model is not sensitive to parameter changes.

The constructed model still has many limitations in reflecting the real conditions at PT ASA. Therefore, there are still many weaknesses in this model. Hence, further development is needed, considering several aspects, including the need for a reorder point to control inventory stability and the consideration of discounts offered by suppliers.

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