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Supplier Selection for Food Industry: A Combination of Taguchi Loss Function and Fuzzy Analytical Hierarchy Process

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ABSTRACT

Supplier selection is an important part of supply chain management process by which firms identify, evaluate, and establish contracts with suppliers. Deciding the right supplier can be a complex task. As such, various criteria must be taken into account to choose the best supplier. This study focused on the supply in the packaging division of a food industry in Denpasar-Bali. A combination of Taguchi Loss Function and fuzzy-AHP (Analytical Hierarchy Process Fuzzy Linear Programming) was used to determine the best supplier. In this analysis, several suppliers' criteria were considered, namely quality, delivery, completeness, quality loss and environmental management. By maximizing the suppliers' performances based on each criterion and aggregating the suppliers' performances based on the overall criteria, the best supplier was determined.

Keywords: supplier selection, taguchi loss function, AHP, fuzzy linear programming,environment

1. Introduction

Nowadays, supply chain management has received renewed interest in the industrial world. In particular, supplier selection problem is of great importance because it has a significant influence on the quality of the goods produced. Therefore, it is necessary to consider the essential parameters before arriving at the right decision for the supplier.

Previously, supplier selection process has been based solely on price criterion, which resulted in companies engaging many short-term agreements with suppliers with the lowest price quotation. As time progresses, however, more emphasis has been put on several additional criteria other than the price.

According to Sarkis and Talluri (2002), the buyer-supplier relationships based solely on price criterion are no longer applicable. The importance of supplier selection requires re-thinking of its procurement strategy and careful evaluation of the procurement decisions in order to be able to select the right supplier. The evaluation and selection of suppliers in the modern context needs to incorporate more criteria, such as supplier quality, the risk of rejection of goods, and delivery time.

This study examines the problems encountered by a food industry in Denpasar, Bali which currently selects a packaging supplier based solely on price criterion. The company management deems it necessary to assess other criteria in the supplier selection process. This research refers to the works by

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Indrapriyatna et.al. (2010), Sevkli *et al*. (2008) and Pi and Low (2005). The proposed method is an integration of fuzzy-AHP method and the Taguchi Loss Function for the process of selecting suppliers in a packaging division of this food industry in Denpasar. AHP is used to determine the relative importance of selection criteria. Taguchi loss function is used to determine the potential losses that occur as a consequence of the allocation of goods to each supplier based on predefined selection criteria. Fuzzy theory is used due to the fact that the characteristics of supplier selection problems tend to be fuzzy. The often encountered fuzziness (vagueness) in the selection process is a result of uncertainty and incomplete information from the selection criteria (Amid and O 'Brien, 2006).

2. Literature Review

2.1. Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is a method discovered by Saaty (1994) (Nydick and Hill, 1992). It is a method for ranking several decision alternatives and selecting the best one when the decision maker has multiple objectives, or criteria, on which to base the decision (Taylor, 2010). The decision maker makes a decision based on how the alternatives compare according to several criteria. The decision maker will select the alternative that best meets the decision criteria. Numerical scores are assigned to rank each decision alternative based on how well the alternative meets the decision maker's criteria. Guller (2008) said that AHP is very useful for managers to formulate the desired decision-making criteria, provide a guideline to determine the level of importance of different decision-making criteria, and then obtain the best decision.

2.2. Taguchi Loss Function

Taguchi loss function (Quality loss function) is a method of measuring loss as a result of the product not meeting the standard specifications (Taguchi, 1989). The purpose of calculating loss is to quantitatively evaluate the quality loss caused by the variation. Loss Function considers the willingness of consumers to obtain a more consistent product and the company's desire to produce products with low cost. Minimization of losses suffered by consumers is a strategy that encourages uniformity of the products and reduces costs of production and consumption. Taguchi loss is useful for the company to identify not only the rejected and reworked scrap but also the possibility of environmental pollution, the use of not long-lasting products, or other negative effects. Loss for the company is the cost due to deviation from the target value.

The concept behind the Taguchi's Quadratic Loss Function (QLF) is to calculate the amount of loss for the company. QLF is a mathematical model that links quality loss to the value of money resulting from the deviation of the quality of the specification from the desired target. Loss in question is the cost of maintenance, the cost of failure, adverse effects to the environment such as pollution or excessive production cost. Based on the loss function approach, the quality characteristics measured by Taguchi can be divided into three categories, namely:

- Nominal the best: It is a quality characteristics value which can be positive or negative. Values are measured by predetermined target value. The closer it gets to the target value, the better the quality.
- Lower the better: It is a non-negative measurable characteristics with respect to the ideal value of zero. The nearer it gets to zero, the better the quality.
- Higher the better: It is a non-negative measurable characteristics value with respect to the ideal value of infinity. The closer it approaches infinity, the better the quality.

Formulation for the loss function is as follows:

a. Nominal the best (L) = $k\,(S^2 + [y - m]^2)$ (1)

b. Lower the better (L) = $k(S^2 + y^2)$ (2)

c. Higher the better (L) = $k\left(\frac{1}{y^2}\right)\left(1 + \frac{3S^2}{y^2}\right)$ (3)

Where:

k = $\frac{A_0}{\Delta_0^2}$

L = loss	m = target	A_0 = cost due to loss
y = measured value	S^2 = variance of distribution	Δ_0 = tolerance
k = loss constant	y = average distribution	

2.3. Fuzzy Linear Programming

Fuzzy Linear Programming is a method of linear programming using the consideration of human thinking in distinguishing qualitative information. By using this method, the conditions arising from the dominant subjectivity and intuition can be resolved, not only based on the assumption of certainty as in the typical linear programming. Bellman and Zadeh (1970) suggested a fuzzy programming model for decision making in a fuzzy environment. Later, their method was first used by Zimmermann (1978) to solve fuzzy multi-objective linear programming problems. In addition to Zimmermann, there are also other studies which used fuzzy-AHP approach, such as Sevkli *et al.* (2008) and Indrapriyatna *et al*. (2010). In this sub-section, the general fuzzy multi-objective model for supplier selection for *m* criteria is described in the following equation:

$$\max \ Z_K = \sum_{i=1}^{n} C_{ki}.X_I \geq Z_k^0 \ , where \ k = 1,2,3,....,m \qquad (4)$$

and constraints:

$$\sum_{i=1}^{n} X_i = 1 \qquad (5)$$

where:

Z_k = objective function for criteria *k*

C_{ki} = supplier value for criteria *k*

X_i = the *i*-th supplier

Every objective function value, Z_k, changes linearly from $Z_k^{\min}$ to $Z_k^{\max}$. So it may be considered as a fuzzy number with the linear membership function μ_{zk} as shown in Figure 1. $Z_k^{\min}$ and $Z_k^{\max}$ are obtained through solving the multi-objective problem as a single objective.

$$\mu_{zk} \begin{cases} 1 & for \ Z_k \geq Z_k^{\max} \\ \dfrac{Z_k^{\max} - Z_k(x)}{Z_k^{\max} - Z_k^{\min}} & for \ Z_k^{\min} \langle Z_k \langle Z_k^{\max} \\ 0 & for \ Z_k \leq Z_k^{\min} \end{cases}$$

Fig.1. Fuzzy Linear Membership Function

If Equation (4) is added to the value of non-negativity of the X_i suppliers, it will be the following linear Program (Zimmermann, 1978):

$$Max\ Z = \sum_{k=1}^{m} w_k \times \lambda_k \tag{6}$$

subject to:

$$\lambda_k \leq \mu_{Zk} \tag{7}$$

$$Xi \geq 0$$

$$\sum_{k=1}^{m} w_k = 1, w_k \geq 0 \tag{8}$$

Where w_k and μ_{Zk} represent the solution of membership function, weighting coefficients that present the relative importance among the fuzzy goals and membership function of the objective function. λ_k is the minimization of the objective function μ_{Zk}.

AHP method is often combined with Fuzzy Linear Programming in the decision-making process. Fuzzy objective and fuzzy constraint used in the optimization of Fuzzy Programming vagueness serve to accommodate the information that occurs in the supplier selection problem with no precise criteria (Zimmerman, 1978).

The combination of AHP-Fuzzy Linear Programs has been demonstrated by Sevkli *et al*. (2008). Pi and Low (2005) combined the AHP with the Taguchi Loss Function in the selection of suppliers. Indrapriyatna *et al*. (2010) utilized AHP-Fuzzy-Taguchi combination in his works. This study adds another criterion (environmental management) and utilize Taguchi Loss Function (Zimmerman, 1978), which will then be integrated with the AHP and resolved by fuzzy linear programming.

3. Research Methodology

The steps to find a good supplier for the company by integrating the Taguchi Loss Function with Fuzzy AHP are schematically described as follows (workflow of this research is shown in figure 2):

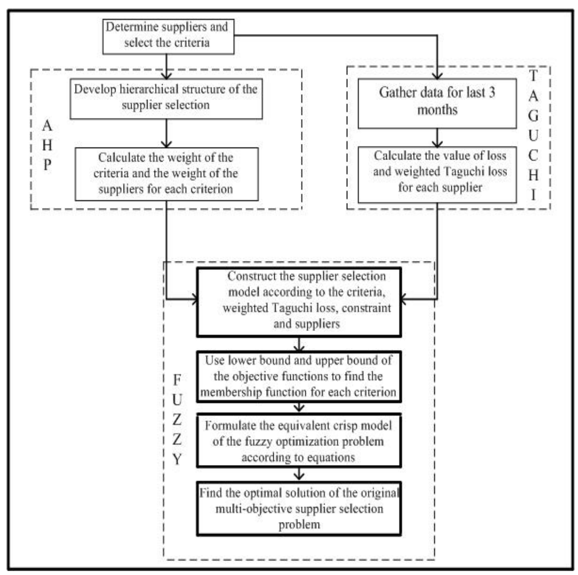

Fig. 2. Diagrammatic Representation of the Research Workflow

1) Determine the suppliers and select the criteria for the supplier selection. This step can be done by interviewing the purchasing Head, the QC head, and the head of production.
2) Develop hierarchical structure of the supplier selection. Perform pairwise comparison of each of the selection criteria and pairwise comparison of the supplier (for each criterion) that can later be used to calculate the weight of the criteria and the weight of the suppliers for each criterion. From the pairwise comparison, Consistency Ratio (CR) can be calculated. If CR $\leq$ 0.1, then the results of the evaluation criteria correspond to acceptable suppliers.
3) Calculate the value of loss by looking for data from the last three months by using equation (1), (2) or (3) based on predetermined criteria. Subsequently, the weighted Taguchi loss for each supplier is calculated. The value of weighted Taguchi loss is the sum of the multiplication of the weight criteria with the loss criteria. Normalized value of the weighted Taguchi loss is obtained by dividing the value of the total loss weighed Taguchi with the Taguchi loss weighted value of each supplier.
4) Construct the supplier selection model according to the criteria, weighted Taguchi loss, constraint and suppliers. Find the lower bound $Z_0^{\min}$ and upper bound $Z_0^{\max}$ to solve the multi-objective supplier selection problem as a single-objective linear programming model. Use lower bound and upper bound of the objective functions to find the membership function for each criterion in equation (4) and equation (5).
5) Based on AHP-Taguchi Loss weighted model, formulate the equivalent crisp model of the fuzzy optimization problem according to equations (6), (7) and (8). Solve problem using Scilab software.
6) Find the optimal solution of the original multi-objective supplier selection problem.

4. Results and Discussion

Based on interviews with the Head of Purchasing, Head of QC Section and Head of Production, it was found that all packaging suppliers offer similar prices. This implies that the price criterion is no longer relevant to be used as a basis in selecting suppliers. Based on some historical data, it is agreed that there are four criteria to be used in the selection of suppliers, i.e. quality, delivery, completeness and environmental management.

Quality is measured from how close the goods are to the manufacturer's specifications. Delivery is measured from the ability of suppliers to deliver the goods on time according to the agreed arrangement. Completeness is measured from the degree of matching between the amount of goods provided by the suppliers and the amount ordered by the company. Finally, environmental management is measured from the physical condition of the supplier’s workplace with respect to the company standards. In our case, the company has three possible suppliers for packaging: Supplier1, Supplier2 and Supplier3.

Calculation of weights was carried out using the AHP supplier. After selected the suppliers and established the suppliers’ criteria, pairwise comparisons were carried out to find out the normalized weighted value of each supplier and each criterion. Pairwise comparison for each supplier for each criterion can be seen in Table 1. Pairwise comparison for each criterion can be seen in Table 2.

Supplier	1	2	3	weighted	CI=0.003
1	1.00	0.50	0.33	0.163	
2	2.00	1.00	0.50	0.297	
3	3.00	2.00	1.00	0.539	
	5.00	4.50	1.83	1.000	CR = 0.005

Supplier	1	2	3	weighted	CI=0.037
1	1.00	0.33	3.00	0.272	
2	3.00	1.00	4.00	0.608	
3	0.33	0.25	1.00	0.120	
	4.33	1.58	8.00	1.000	CR=0.064

Completeness

Supplier	1	2	3	weighted	CI=0.027
1	1.00	0.25	0.50	0.133	
2	4.00	1.00	4.00	0.655	
3	2.00	0.25	1.00	0.211	
	7.00	1.50	5.50	1.000	CR=0.047

Environmental Management

Supplier	1	2	3	weighted	CI=0.009
1	1.00	0.25	0.33	0.123	
2	4.00	1.00	2.00	0.557	
3	3.00	0.50	1.00	0.320	
	8.00	1.75	3.33	1.000	CR=0.016

Table 2. Pairwise Comparison for Criteria

Criteria	Quality	Delivery	Completeness	Environmental	weighted	
Quality	1.000	2.000	2.000	3.000	0.423	
Delivery	0.500	1.000	2.000	2.000	0.271	CI= 0.015
Completeness	0.500	0.500	1.000	1.000	0.162	CR =0.017
Environmental	0.333	0.500	1.000	1.000	0.144	

For quality criteria, the normalized weighted value of Supplier1, Supplier2, and Supplier3 are 0.163, 0.297, and 0.539, respectively, and the Consistency Index (CI) is 0.003. For delivery criteria, the normalized weighted value of Supplier1, Supplier2, and Supplier3 are 0.272, 0.608, and 0.120, respectively, and the CI value is 0.037. For completeness criteria, the normalized weighted value of Supplier1, Supplier2, and Supplier3 are 0.133, 0.655, and 0.211, respectively, and the CI value is 0.027. For environmental management criteria, the normalized weighted value of Supplier1, Supplier2, and Supplier3 are 0.123, 0.557, and 0.320, respectively, and the CI value is 0.009. The value of Consistency Ratio (CR) is obtained by dividing CI with Random Index (0.58). If CR < 0.1, it means the degree of consistency is satisfactory. Since CR for all of our results it means that the management evaluation for all criteria is acceptable or consistent. The normalized weighted value for each criterion, i.e. quality, delivery, completeness, and environmental management, are 0,423; 0,271; 0.162; and 0,144, respectively.

Based on the January-March 2012 records in the Purchasing Department, the following data for goods deficit, amount of defective products as received from suppliers, suppliers' performance based on delivery criteria and environmental management data were obtained as shown in Table 3. Historical data for defective products were used for the Quality criteria. If supplier delivers a product matching the specification, the assigned value is 0, and 1 if otherwise. Delivery historical data were used for delivery criteria. If supplier delivers on-time, the assigned value is 0 and if the delivery is late, the assigned value is 1, with unit of weeks as the reference. Goods deficit data were used for the completeness criteria. If supplier deliver goods precisely as ordered, 0 is assigned, and 1 if the amount is less than that in the purchase order. For these four criteria, the loss calculation used the-lower-the-better method. Historical data for supplier environmental management criteria were obtained from the auditing process on the suppliers' working environment. This assessment was carried out by a professional in the field of environmental audit. If the suppliers' physical condition meets the company standards, 0 is assigned, and 1 if otherwise.

Criteria specification limits and the corresponding penalties imposed on the suppliers should there be violations against the rules are shown in Table 4. The specification limits and the penalties were determined by the company according to the contract agreed upon with the supplier, based on the memo from the Head of Purchasing Department.

Table 3. Historical Data

Goods Deficit Data			
	Supplier		
Month	A	B	C
January	1	1	0
February	0	0	0
March	0	0	0

Defective Products Data			
	Supplier		
Month	A	B	C
January	1	0	0
February	0	1	0
March	1	0	1

Late Delivery Data			
	Supplier		
Month	A	B	C
January	0	0	0
February	0	0	1
March	1	0	0

Non-recyclable Products Data			
	Supplier		
Month	A	B	C
January	1	1	1
February	0	1	1
March	0	1	0

Table 4. Criteria Specification Limits and Costs Due to Violations

Criteria	**Target**	**Tolerance**	**Loss calculation**	**Cost**
Quality	0 (no defective products)	max 3	lower the better	85000
Delivery	0 (punctual)	at most 4 days	lower the better	75000
Completeness	0 (amount of goods as ordered)	max 3	lower the better	85000
Environmental management	0 (meets the standard)	1 (sub-standard)	lower the better	60000

The loss value of each criterion were calculated from equation (2), while the weighted Taguchi value is the loss value multiplied by the weight value of each criterion. The calculation of loss, weighted Taguchi, and normalized values are summarized in Table 5.

Table 5. Loss Value Calculation for Each Criterion

	quality	delivery	completeness	environmental management	weighted Taguchi	normalized
1	52469	10417	20988	133333	47617	0.231
2	20988	0	20988	600000	98678	0.479
3	20988	10417	0	333333	59701	0.290

Based on pairwise comparison of suppliers for each criterion and calculated normalized loss, a multi-objective fuzzy linear programming model to select packaging supplier was developed. This stage involves construction of multi-objective linear programming model as a single-objective supplier selection problem using only one objective each time. The multi-objective linear programming of our application is presented as max Z_1 to Z_5.

Max $Z_1 = 0.163X_1 + 0.297\ X_2 + 0.539\ X_3$

Max $Z_2 = 0.272\ X_1 + 0.608\ X_2 + 0.120\ X_3$

Max $Z_3 = 0.133\ X_1 + 0.655\ X_2 + 0.211\ X_3$

Max $Z_4 = 0.123\ X_1 + 0.557\ X_2 + 0.320\ X_3$

Max $Z_5 = 0.231\ X_1 + 0.479\ X_2 + 0.290\ X_3$

S/T

$X_1 + X_2 + X_3 = 1$

$X_1, X_2, X_3 \geq 0$

Then, the linear membership function is used for fuzzifying the objective functions and the constraints for the above problem. The data set for the values of the lower bounds $Z_k^{\min}$ and upper bounds $Z_k^{\max}$ of the objective functions are provided in Table 6.

Table 6. Data Set for the Membership Functions

	$Z_k^{\max}$ (μ=1)	$Z_k^{\min}$ (μ=0)
Z_1-Quality	0.539	0.163
Z_2-Delivery	0.608	0.120
Z_3-Completeness	0.655	0.133
Z_4-Environmental Management	0.557	0.123
Z_5- Loss	0.479	0.231

In this stage, the membership functions for five objective functions and the constraints are provided to maximize the performance of suppliers related to each main supplier selection criterion. To exemplify, we take the performance assessment criteria to show the membership function of Z1. The objective of each membership function is to maximize the supplier criteria and minimize the loss value. The membership functions are formulated as shown earlier in Figure 1. The membership functions of supplier selection model for food industry are formulated as shown in Figure 3.

$$\mu_{Z1}\begin{cases} 1 & for\ Z_k \geq 0.539 \\ \dfrac{0.539 - Z_k(x)}{0.539 - 0.163} & for\ 0.163 \langle Z_k \langle 0.539 \\ 0 & for\ Z_k \leq 0.163 \end{cases} \qquad \mu_{Z2}\begin{cases} 1 & for\ Z_k \geq 0.608 \\ \dfrac{0.608 - Z_k(x)}{0.608 - 0.120} & for\ 0.120 \langle Z_k \langle 0.608 \\ 0 & for\ Z_k \leq 0.120 \end{cases}$$

$$\mu_{Z3}\begin{cases} 1 & for\ Z_k \geq 0.655 \\ \dfrac{0.655 - Z_k(x)}{0.655 - 0.133} & for\ 0.133 \langle Z_k \langle 0.655 \\ 0 & for\ Z_k \leq 0.133 \end{cases} \qquad \mu_{Z4}\begin{cases} 1 & for\ Z_k \geq 0.557 \\ \dfrac{0.557 - Z_k(x)}{0.557 - 0.123} & for\ 0.123 \langle Z_k \langle 0.557 \\ 0 & for\ Z_k \leq 0.123 \end{cases}$$

$$\mu_{Z5}\begin{cases} 1 & for\ Z_k \geq 0.479 \\ \dfrac{0.479 - Z_k(x)}{0.479 - 0.231} & for\ 0.231 \langle Z_k \langle 0.479 \\ 0 & for\ Z_k \leq 0.231 \end{cases}$$

Fig. 3. The Membership Function of Supplier Selection Model for Food Industry

The fuzzy multi-objective formulation of the application as in equations (4) and (5) is shown below.

Max $Z_1 = 0.163X_1 + 0.297\ X_2 + 0.539\ X_3 \geq Z_1^0$
Max $Z_2 = 0.272\ X_1 + 0.608\ X_2 + 0.120\ X_3 \geq Z_2^0$
Max $Z_3 = 0.133\ X_1 + 0.655\ X_2 + 0.211\ X_3 \geq Z_3^0$
Max $Z_4 = 0.123\ X_1 + 0.557\ X_2 + 0.320\ X_3 \geq Z_4^0$
Max $Z_5 = 0.231\ X_1 + 0.479\ X_2 + 0.290\ X_3 \geq Z_5^0$
S/T
$X_1 + X_2 + X_3 = 1$
$X_1, X_2, X_3 \geq 0$

After the membership functions were obtained, with the help of equations (6), (7), and (8), the single Taguchi Loss Function-Fuzzy-AHP can be constructed as follows:

Max $w_1\ (0.423\ \lambda_1 + 0.271\ \lambda_2 + 0.162\ \lambda_3 + 0.144\ \lambda_4) + w_2\ (\lambda_5)$
S/T

$$\lambda_i \geq \frac{Z_k^{\max} - Z_k(x)}{Z_k^{\max} - Z_k^{\min}}$$

$X_i = 1$
$X_i \geq 0$
$0 \geq \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5 \geq 1$

w_1 is weight for criteria and w_2 is weight for the loss, where $w_1 + w_2 = 1$. Based on discussions with the head of purchasing and production, the obtained value for w_1 is 0.8 and the value for w_2 is 0.2, such that:
Max $0.3384\ \lambda_1 + 0.2168\ \lambda_2 + 0.1296\ \lambda_3 + 0.1152\ \lambda_4 + 0.2\ \lambda_5$
S/T

$$\lambda_1 \geq \frac{0.539 - (0.163X_1 + 0.297X_2 + 0.539X_3)}{0.539 - 0.163}$$

$$\lambda_2 \geq \frac{0.608 - (0.272X_1 + 0.608X_2 + 0.120X_3)}{0.608 - 0.120}$$

$$\lambda_3 \geq \frac{0.655 - (0.133X_1 + 0.655X_2 + 0.211X_3)}{0.655 - 0.133}$$

$$\lambda_4 \geq \frac{0.557 - (0.123X_1 + 0.557X_2 + 0.320X_3)}{0.557 - 0.123}$$

$$\lambda_5 \geq \frac{0.479 - (0.231X_1 + 0.479X_2 + 0.290X_3)}{0.479 - 0.231}$$

$X_1 + X_2 + X_3 = 1$
$X_1, X_2, X_3 \geq 0$
$0 \geq \lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5 \geq 1$

After the model of Taguchi loss function is created, the problem is solved using Scilab software to obtain $X_1 = 1$, $X_2 = 0$ and $X_3 = 0$, meaning that the selected supplier is Supplier 1. When each value of X_i is substituted into the objective function, Z_i values are obtained.

$Z_1 = 0.163$, $Z_2 = 0.272$, $Z_3 = 0.133$, $Z_4 = 0.123$, $Z_5 = 0.231$.
$\lambda_1 = \mu_{Z1} = 1$
$\lambda_2 = \mu_{Z2} = 0.689$
$\lambda_3 = \mu_{Z3} = 1$
$\lambda_4 = \mu_{Z4} = 1$
$\lambda_5 = \mu_{Z1} = 1$

The obtained values for each membership function show that the achievement levels of Z_1– quality criteria, Z_3 – completeness criteria, Z_4 – environmental management criteria and Z_5 – loss are higher than Z_2 – delivery criteria. In other words, the achievement level of the objective functions corresponds to the priority of supplier selection criteria (based on decision maker's preferences) and indicates that Supplier 1 is selected as the optimum supplier.

5. Conclusion and Recommendation

The aim of this study was to perform supplier selection to choose the best supplier by integrating the Taguchi Loss Function with Fuzzy-AHP with respect to several criteria, namely the quality, delivery, completeness, and environmental management.Based on the results of data processing, it can be concluded that by integrating the Taguchi loss function with Fuzzy-AHP, Supplier 1 was found to be the best packaging supplier alternative. Future studies are expected to add other criteria, such as risk factors and uncertainty factors. In addition, further research can use other methods such as combining fuzzy-AHP method with a utility function.

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