MULTI CRITERIA SUPPLIER SELECTION USING A HYBRID FUZZY AHP- TAGUCHI TECHNIQUE (Case Study: a Textile Company)

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ABSTRACT

This paper discusses a method that integrates Fuzzy AHP with Taguchi Loss Function. The method used to select suppliers with various criteria. This various criteria will be considered to get the best supplier. This research was conducted in a textile company for the cotton product 41166. The purpose of this research is to apply techniques to improve the performance of Fuzzy AHP by considering the cost of losses as small as possible. Research data obtained from the survey results using questionnaires and company factual data in the form of costs of losses incurred due to improper quantity of raw materials, quality of raw materials that are not in accordance with standards, delays in delivery, prices that exceed expectations, and poor service or response. The results of this research indicated the value of losses incurred by 1st, 2nd, 3rd, 4th suppliers respectively for $ 2.23, $ 671.12, $ 815.57, and $ 1243.64. Among four suppliers, the best supplier with the smallest loss value is first supplier.

Keywords*: Supplier Selection, Fuzzy AHP, Taguchi Loss Function*

ABSTRAK

Makalah ini membahas metode yang mengintegrasikan Fuzzy AHP dengan Taguchi Loss Function. Metode yang digunakan untuk memilih pemasok dengan berbagai kriteria. Berbagai kriteria ini akan dipertimbangkan untuk mendapatkan pemasok terbaik. Penelitian ini dilakukan di sebuah perusahaan tekstil untuk produk kapas 41166. Tujuan dari penelitian ini adalah menerapkan teknik untuk meningkatkan kinerja Fuzzy AHP dengan mempertimbangkan biaya kerugian sekecil mungkin. Data penelitian diperoleh dari hasil survei dengan menggunakan kuesioner dan data faktual perusahaan berupa biaya kerugian yang timbul akibat kuantitas bahan baku yang tidak tepat, kualitas bahan baku yang tidak sesuai dengan standar, keterlambatan pengiriman, harga yang melebihi ekspektasi, dan layanan atau tanggapan yang buruk. Hasil penelitian ini menunjukkan nilai kerugian yang dialami oleh pemasok ke-1, ke-2, ke-3, ke-4 masing-masing sebesar $ 2,23, $ 671,12, $ 815,57, dan $ 1243,64. Di antara empat pemasok, pemasok terbaik dengan nilai kerugian terkecil adalah pemasok pertama.

Kata kunci*: Pemilihan Pemasok, Fuzzy AHP, Taguchi Loss Function*

INTRODUCTION

In the development of manufacturing industry, one aspect that has become a key success factor in industrial competition is the selection of suppliers. The selection of right supplier can reduce cost of material purchases so consequently improve the competitiveness of a company [1]. A supplier selection is very important because the right procurement decision depends on the right supplier [2]. In an effort to know the suppliers itself, a company need to study the supplier's image as well as its track records [3]. Each company has different supplier criteria, depending on the company's objectives. The criteria must reflect the characteristics of raw materials purchased, whereas each characteristic has a different level of importance. MCDM (Multi Criteria Decision Making) techniques such as AHP, ANP, PROMETHEE, Fuzzy AHP, etc are often used in supplier selection. It needs to consider more criteria, thus the selected supplier is a best priority from various aspects of assessment [4].

This research proposes a hybrid method between Fuzzy AHP and Taguchi Loss Function in process of selecting 41166 cotton fabric suppliers. Fuzzy theory is suitable to be applied, because the characteristics of supplier selection problems tend to be fuzzy

caused by uncertainty and incomplete information from selection criteria [5],[6]. Fuzzy AHP is applied to determine the ranking of each supplier, which integrated with Taguchi Loss Function technique is used to determine the losses incurred as a consequence of the goods allocation to each supplier based on predetermined selection criteria.

LITERATURE REVIEW

Analytical Hierarchy Process, often called AHP, was developed in 1980 by Saaty. AHP is a method for selecting the best decision alternatives based on rank when a decision maker has several criteria. AHP relies on the opinion of an expert to obtain a priority scale [7]. It is commonly used in handling qualitative and quantitative criteria on MCDM Method [8]. However, the application of AHP depends on the perception of experts, the model becomes meaningless if the expert gives a wrong assessment. This method is considered to be less able to handle uncertainty in human judgment so that the solution obtained does not answer the purpose of problem [9].

To avoid the risk of errors in interpretation, an appropriate development method can be used to solve the problem called fuzzy AHP [7]. Fuzzy theory functions to accommodate the obscurity of information that occurs in the selection of suppliers with criteria that are not precise [10]. Fuzzy AHP is based on Fuzzy Logic which modifies set theory where each member has a degree of membership that has continuous values between 0 and 1. This set is called a Fuzzy Set. Fuzzy set is based on an idea of extending the range of characteristic functions so that the function will include real numbers at intervals (0, 1). The membership value indicates that an item in the universe of conversation is not only at 0 or 1, but also the value that is in between. While in the crisp set, the membership value is only 2 possibilities, namely 0 or 1. So, the fuzzy AHP (FAHP) method is a systematic approach in selecting alternatives that involve information in the form of opinions or estimates through the application of both fuzzy set theory concepts and hierarchical structure analysis - AHP [11].

The person who first introduced the concept of fuzzy theory about the obscurity of human thought was Zadeh in 1965 [12]. In 1996, Chang introduced a new approach, using triangular fuzzy numbers for pairwise comparison scales, and used the extent analysis method for synthetic extent from pairwise comparisons [13]. In 1998, Kahraman et.al [11] introduced objective and subjective fuzzy methods using weighting with AHP and fuzzy. In fuzzy AHP, alternatives are sorted by overall weight through the max-min rating application.

Fuzzy theory helps in measuring concepts related to human subjective assessment, using triangular fuzzy linguistics with a triangular fuzzy number (TFN). Triangular fuzzy number is represented by numbers (l, m, u) where the strongest membership level is m, with μ_M (m) = 1, l is the lower limit and u is the upper limit. Table 1 shows the TFN used for purposes of the pairwise comparison matrix. The membership of triangular fuzzy numbers can be described as seen in Figure 1. The membership function is defined as follows:

$$\mu_M(x) = \begin{cases} \frac{x-l}{m-l}, l \le x \le m \\ \frac{u-x}{u-m}, m \le x \le u \\ 0, \quad \text{Otherwise} \end{cases} \quad \text{where } -\infty < l \le m \le u < \infty \qquad (1)$$

Table 1. Fuzzy Scale and its Linguistic Description [14]

Fuzzy Scale Intensity	The Opposite of a Fuzzy Scale	Definition of Linguistic Variables
1 = (1,1,3)	(1/3, 1/1, 1/1)	Equally important (denoted as "SM")
3 = (1,3,5)	(1/5, 1/3, 1/1)	Weak or a little more important (denoted as "SLP")
5 = (3,5,7)	(1/7, 1/5, 1/3)	More important (denoted as "LP")
7 = (5,7,9)	(1/9, 1/7, 1/5)	Very important (denoted as "SP")
9 = (7,9,9)	(1/9, 1/9, 1/7)	Absolute more important (denoted as "MLP")
2 = (1,2,4)	(1/4, 1/2 1/1)	Middle value between two ratings
4 = (2,4,6)	(1/6, 1/4 1/2)	
6 = (4,6,8)	(1/8, 1/6, 1/4)	
8 = (6,8,9)	(1/9, 1/8, 1/6)	

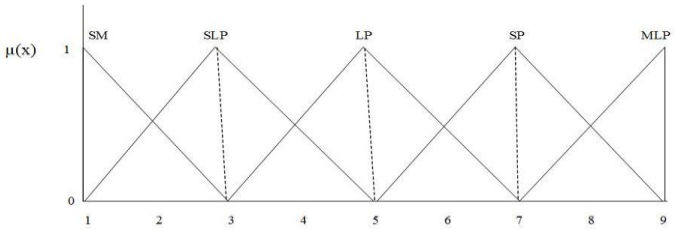

Figure 1. Set of Fuzzy Triangular Numbers [15]

TFN is useful for describing and processing information in a fuzzy scale. The core of fuzzy AHP lies in pairwise comparisons which are described by the ratio scale [16]. TFN expresses "around x" at intervals of $1 \leq x \leq 9$ as shown in Table 2.

Table 2. Membership Function of Fuzzy Number [17]

Fuzzy Number	Membership Function
1	(1,1,3)
2	(1,2,4)
x	(x-2, x, x+2) = (3,5,7)
8	(6,8,9)
9	(7,9,9)

The application of this method is considered insufficient because it does not take into account the value of losses from each supplier. Taguchi loss function is an effective method for engineering quality, because it takes into account the suitability of goods with predetermined specifications [5]. The purpose of the taguchi loss function is to evaluate the quality loss quantitatively due to variations [18]. Taguchi method was introduced by Dr. Genichi Taguchi [18] in 1949 when he got the task to improve the telecommunications system in Japan. Genichi Taguchi developed a design approach from the perspective of robust design, where products must be designed to be free from defects and high quality. Genichi Taguchi has an idea about quality engineering where the quality design goals are applied to each product and its related processes.

He provides three concepts that aim to improve product quality and process, namely; quality robustness, quality loss function, and target oriented quality. In this study more emphasis and discussion about Taguchi Loss Function (TLF). This technique identifies all costs related to low quality and shows how these costs increase if the quality of the product is further away from the customer's desires. These costs not only include customer dissatisfaction, but also warranty and service costs, internal inspection fees, repairs, scrap, and other costs that are considered as costs to the community. Quality loss function is used to find out how much the expected losses are borne by the company. Expected losses are

obtained when the output of products produced in the production process does not meet the set targets [19].

METHOD

This research was conducted in a textile company by taking primary and secondary data. The first step is to determine the criteria that influence supplier selection by conducting interviews with several purchasing and marketing department staff. Then based on these criteria a hierarchical structure was created and data collection was carried out using a questionnaire distributed to employees who have worked in the company for more than 3 years. This questionnaire was used to determine the weight of each criterion in supplier selection and compare each supplier alternative in meeting each given criteria.

Based on the results of questionnaire, paired comparison was carried out for each respondent. Then do fuzzification to change the value of crisp to triangular fuzzy number. Fuzzification is done to minimize the subjectivity in the questionnaire assessment. After obtaining a fuzzy value, the value is changed back to the new crisp value so that it can be normalized to get the eigen vector value. The next step is to calculate the consistency ratio (CR) to find out whether the questionnaire is consistent and can be used, if the questionnaire data from each respondent is consistent then the Geometric Mean can be calculated using the equation below.

$$Geomean = \sqrt[n]{S1 \times S2 \times S3 \times \ldots \times Sn} \quad (2)$$

The next step is to compare fuzzy synthetic extent values for each sub-criteria and alternative suppliers, then maximize and minimize operations to get the weight values of each supplier's criteria and alternatives. This weight will be integrated into the Taguchi Loss Function Technique.

$$V(M_2 \geq M_1) = \begin{cases} 1, & if\ m_2 \geq m_1 \\ 0, & else\ if\ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \quad (3)$$

The next stage is to identify the costs that arise related to each criterion for each supplier. Before calculating the target value, it is necessary to calculate the constant value first. Here is the formula to find the value of constant losses.

$$L(x) = k \times (x - t)^2 \quad (4)$$

Where, $L(x)$ is loss in currency units, k is a loss constant, x is the highest value of product sales, t is the normal value of product sales.

Next we identify the type of quality loss function of each criterion where there are 3 types of target that need to be achieved. The first type is nominal the best has the understanding that it is better to be within the tolerance limit or a predetermined target. Criteria such as quantity and delivery are included in this target type, nominal the best. Where the Taguchi equation for calculating the losses caused by the product can be stated as follows:

For 1 unit product

$$L(y) = k\,(y - m)^2 \quad (5)$$

For more than 1 unit product

$$L\,(y) = k\,[\sigma^2 + (y - m)^2] \quad (6)$$

The second type, smaller the better has the understanding that it is better to choose the least value. Criteria such as price, quality, and service are included in this type, smaller the better. Where the Taguchi equation for calculating the losses caused by the product can be stated as follows:
For 1 unit product

$$L(y) = k \times y^2 \quad (7)$$

For more than 1 unit product

$$L(y) = k\,(\sigma^2 + y^2) \quad (8)$$

Where, y is the quality characteristic of finished product, $L(y)$ is the loss of a currency unit when the product characteristics are equal to "y", m is quality characteristic that is the real "y" target, k is a loss constant, σ is standard deviation, y^2 is a tolerance value determined by the company.

The third type, largest the best states that the greater the target value achieved, the better the quality of a product. Where the Taguchi equation for calculating the losses caused by the product can be stated as follows:

For 1 unit product

$$L(y) = k\frac{1}{y^2} \quad (9)$$

$$k = A_0.\Delta^2 \quad (10)$$

For more than 1 unit product

$$L(y) = k\,(MSD) \quad (11)$$

$$L(y) = \frac{k}{\mu^2}\left[1 + \frac{3\sigma^2}{\mu^2}\right] \quad (12)$$

The last step is to multiply the calculation results from the loss function with the weight of each criterion from the previous results. The total losses for each criterion will be multiplied by the weight of each criterion. The results of this calculation will determine the value of losses arising from each supplier.

RESULTS AND DISCUSSION

Fuzzy AHP

Table 3 shows the viewpoint of each supplier selection criterion for this study. These perspectives are grouped into 10 criteria which can be seen in table below.

Table 3. Selection Criteria and its Viewpoint

Code	Criteria	Assessment Viewpoint
QOP	Quality of product	• Usability (final destination of goods or products sold) • Durability (economic expectation of a product) • Get the raw material of gray fabric with the right quality • Producing quality fabric products • A reliability of the product to perform its functions during economic times
QP	Quality philosophy	• A conformance of the product to be able to meet the specified descriptions and specifications • Producing finished goods in accordance with international standards • Ability to produce consistent quality
CBI	Conformance of budget item cost	• Price per yard of fabric raw material from suppliers will be selected according to other costs
CE	Cost effectiveness	• Low total costs such as discounts, shipping costs arrive at the place • Payment method or payment period (payment terms)
RES	Responsiveness	• Ease of returning products that are not in accordance with agreed or standard specifications • Ability to provide information clearly and easily understood • Speed in response to customer requests • Be responsive in resolving customer complaints

Continued Table 3. Selection Criteria and its Viewpoint

Code	Criteria	Assessment Viewpoint
WAC	Warranties and claim policies	• Provide guarantees for goods • Provide assistance in an emergency • Provide compensation policies
PHP	Performance history and reputation	• Ability to fulfill the number of orders • Ability to maintain contractual agreements • Ability to fulfill quantity against a predetermined schedule • Good name and business experience (length of business in a certain field)
MO	Management and organization	• Good management and organization conditions • Completeness of company documents • Completeness of the goods offer documents • Certification
COD	Conformance of delivery	• Timeliness of fabric delivery • The accuracy of quantity delivered • Quality of goods received • Lead time
FLE	Flexibility	• Ease in adding or reducing raw material purchases • Ease of changing delivery schedules

The object of research was suppliers of 41166 raw material. There were 4 alternative suppliers to be selected. Elements of the hierarchical structure determined consist of 3 levels, namely objectives, main criteria, and alternative suppliers, as illustrated in Figure 2.

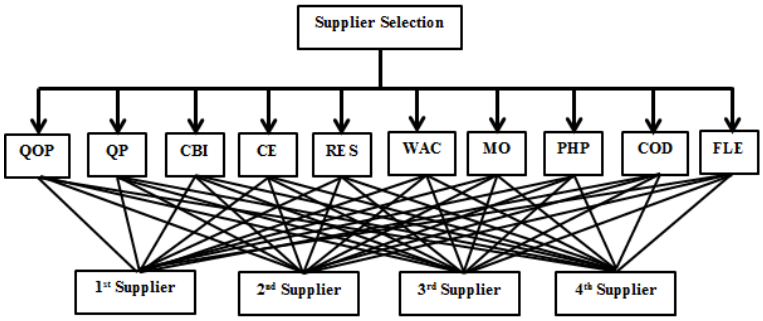

Figure 2. A hierarchical structure of decision

First of all, the weight value of AHP is converted to Triangular Fuzzy Number. Furthermore, the consistency of these results was tested. Then the lower, middle, and upper values are combined to calculate Fuzzy synthetic extent values for each criterion. The fuzzy synthetic comparison results indicate the weight or ranking of each alternative supplier, as shown in Table 4.

Table 4. Results of Fuzzy Synthetic Comparison

Alternative	QOP	QP	CBI	CE	RES	WAC	PHP	MO	FLE	COD	weight
	0.1311	**0.0778**	**0.1040**	**0.0922**	**0.1070**	**0.0997**	**0.0877**	**0.0662**	**0.1168**	**0.1173**	
Supplier #1	0.5854	0.8729	0.0984	0.3140	0.2948	0.3155	0.3046	0.2764	0.2597	0.4427	0.3742
Supplier #2	0.2275	0.1271	0.3864	0.2643	0.2771	0.2970	0.3046	0.2605	0.2567	0.2829	0.2707
Supplier #3	0.1871	0.0000	0.2953	0.1508	0.2279	0.2881	0.2225	0.2762	0.2238	0.1559	0.2045
Supplier #4	0.0000	0.0000	0.2199	0.2708	0.2000	0.0995	0.1682	0.1868	0.2597	0.1185	0.1505

To further simplify the integration phase with Taguchi Loss Function, not all of the criteria analyzed further have impact their costs. Based on discussions with company management, it was agreed that the criterion, which has a weight of below 0.10, could be ignored. Therefore, there are only 5 criteria are discussed in more detail using the Taguchi method approach, as shown in Table 5. The top ranking for alternative suppliers based on Fuzzy AHP method is 1-2-3-4. This weight would be integrated into the calculation of Taguchi Loss Function.

Table 5. Final Result of Fuzzy AHP

Alternative	QOP	CBI	RES	FLE	COD	Weight
	0.2169	**0.1821**	**0.1876**	**0.2102**	**0.2031**	
Supplier #1	0.5854	0.0984	0.2948	0.2597	0.4426	0.3447
Supplier #2	0.2275	0.3864	0.2771	0.2567	0.2828	0.2831
Supplier #3	0.1870	0.2952	0.2279	0.2238	0.1559	0.2158
Supplier #4	0.0000	0.2199	0.2000	0.2597	0.1185	0.1562

Taguchi Loss Function

As mentioned before, there are 5 criteria in supplier selection which will be discussed in more detail using the Taguchi method approach, namely quality of product, conformance of item budget, responsiveness, conformance of delivery, and flexibility. Based on historical data from August 2016 to September 2017 from purchasing department, the following data is obtained. Table 6 indicates the performance of each supplier in terms of the quantity of goods delivered, Table 7 shows the performance of each supplier in terms of the timeliness of delivery, Table 8 indicates the performance of each supplier in terms of whether the goods are delivered in defects, Table 9 indicates the performance of each supplier reviewed from the price of goods, while Table 10 indicates the performance of each supplier in terms of the speed of supplier response.

Table 6. Quantity of Goods

Month	Alternative Supplier			
	#1	#2	#3	#4
Aug-2016	0	+	0	0
Sep-2016	0	0	0	+
Feb-2017	0	0	0	+
Jun-2017	+	0	0	0
Sep-2017	0	0	+	-

The quantity of goods received according to order is given a value of 0. If there is excess, it is given a positive sign, otherwise if it is less than the order it is given a negative sign.

Table 7. Delivery Performance

Month	Alternative Supplier			
	#1	#2	#3	#4
Aug-2016	0	+	-	0
Sep-2016	0	0	0	-
Feb-2017	0	0	0	0
Jun-2017	0	0	0	0
Sep-2017	+	0	-	0

Supplier delivers goods on time given a value of 0. If the goods are delivered faster than the time set then given a positive sign, on contrary if the goods are delivered late or longer than the time set then given a negative sign.

Table 8. Defect of Goods

Month	Alternative Supplier			
	#1	#2	#3	#4
Aug-2016	0	0	-	0
Sep-2016	0	0	0	-
Feb-2017	0	0	0	0
Jun-2017	0	0	0	-
Sep-2017	0	0	0	0

If the supplier delivers goods that are not in accordance with the requested quality, as well as the item received is defective, then it is given a negative sign. If it is appropriate, then it is given a value of 0.

Table 9. Price

Month	Alternative Supplier			
	#1	#2	#3	#4
Aug-2016	0	0	0	0
Sep-2016	0	0	0	0
Feb-2017	0	0	0	0
Jun-2017	0	0	0	0
Sep-2017	0	0	0	0

If the price offered by the supplier in accordance with the maximum limits and still be within tolerable limits, or in other words, does not result in the company suffered a loss, it can be given a value of 0. On contrary, if the price is above the tolerance limit, it can be given a negative sign.

Table 10. Supplier's Response

Month	Alternative Supplier			
	#1	#2	#3	#4
Aug-2016	0	0	0	0
Sep-2016	0	0	-	0
Feb-2017	0	-	0	0
Jun-2017	0	0	0	0
Sep-2017	0	0	-	-

If the supplier's response is fast or in line with expectations, it is given a value of 0. Whereas, if the supplier's response is slow or not as expected, then a negative sign is given.

Both positive and negative signs cause losses for the company. An example is the delivery performance, given a positive sign if the supplier sends raw materials faster than the schedule should, given a negative sign if the supplier delivers raw materials later than the schedule they should. Late delivery results in a delayed production process or a shorter lead time to reach the customer's hands. Meanwhile, faster delivery results in other additional costs due to production machinery that is not yet available so that raw materials will wait to be processed.

The losses incurred by the company, for errors or violations from each supplier, are different. The average loss per event obtained from the first supplier is $ 0.50, the second supplier is $ 0.47, the third supplier is $ 0.56, and the fourth supplier is $ 0.31. Table 11 shows the results of the loss function values for each criterion.

Table 11. Results of Loss Function Value

Supplier	*Losses Nominal the Best Value*	*Losses Smaller the Better Value*
Supplier #1	$ 3.24	$ 942.24
Supplier #2	$ 0.47	$ 2,369.27
Supplier #3	$ 4.50	$ 1,254.65
Supplier #4	$ 0.38	$ 2,652.44

Table 12 shows the summary of losses of each supplier for each criterion. Furthermore, this result is multiplied by the weight of Fuzzy AHP results for the five criteria to obtain the losses of each supplier, as shown in Table 13.

Table 12. Losses of Each Supplier for Each Criterion

Criteria	Alternative			
	Supplier #1	Supplier #2	Supplier #3	Supplier #4
Quantity	$ 3.24	$ 0.47	$ 4.50	$ 1.13
Delivery	$ 3.24	$ 0.47	$ 8.99	$ 0.38
Service	$ -	$ 2,369.27	$ 2,509.30	$ 2,652.44
Quality	$ -	$ -	$ 1,254.65	$ 5,304.87
Price	$ -	$ -	$ -	$ -

The smallest loss is caused by the first supplier with a loss of $ 2.23. The next consecutive is the second supplier with a loss value of $ 671.12, the third supplier with a loss value of $ 815.37, and finally the fourth supplier with the largest loss value of $ 1243.64, as shown in Table 13. Meanwhile, so far the selection of suppliers is based more on the opinions of the managers and directors of this company where the order of suppliers from the best is the first, second, fourth, and third supplier. But if it is assessed from the losses incurred, the order of suppliers starts with the smallest loss is the first, second, third, and fourth supplier.

Table 13. Losses, Weight and Ranking of Each Supplier

Alternative	Quantity	Delivery	Service	Quality	Price	Total	Weight	Rank
Supplier #1	$ 1.12	$ 1.12	$ -	$ -	$ -	$ 2.23	0.00082	1
Supplier #2	$ 0.13	$ 0.13	$ 670.86	$ -	$ -	$ 671.12	0.24562	2
Supplier #3	$ 0.97	$ 1.94	$ 541.64	$ 270.82	$ -	$ 815.37	0.29841	3
Supplier #4	$ 0.18	$ 0.06	$ 414.47	$ 828.94	$ -	$ 1,243.64	0.45515	4
Total						$ 2,732.37	1.00000	

The results of the integration of AHP-TLF and Fuzzy AHP-TLF show a non-significant difference in total losses, so that this study does not change the ranking of each supplier. This is because the weighting results between the AHP and Fuzzy-AHP methods are not significantly different. However, the integration of the Taguchi Loss Function is considered effective and can reduce subjective bias in supplier selection or other decision making.

Table 14. Results of Ranking for Each Method

Goal	AHP		Fuzzy AHP		AHP-TLF			FAHP-TLF		
	Weight	Rank	Weight	Rank	Total Losses	Weight	Rank	Total Losses	Weight	Rank
Supplier #1	0.370	1	0.374	1	$ 2.34	9E-04	1	$ 2.23	8E-04	1
Supplier #2	0.260	2	0.271	2	$ 641.45	0.234	2	$ 671.12	0.245	2
Supplier #3	0.200	3	0.205	3	$ 755.69	0.276	3	$ 815.37	0.298	3
Supplier #4	0.160	4	0.151	4	$ 1.338.63	0.489	4	$ 1,243.64	0.455	4

CONCLUSION

This study successfully integrates Fuzzy AHP with Taguchi Loss Function in supplier selection by considering the criteria ie quantity, delivery, service, quality, and price. Based on the overall results, it can be concluded that using fuzzy AHP with Taguchi Loss Function integration where the selected supplier for 41166 cotton fabric with the smallest loss value is the first supplier.

The suggestion from this research is that this company should not choose the fourth supplier, because the supplier raises the highest loss value. This company should make improvements in determining the quantity of ordering raw materials, so that orders for the fourth supplier can begin to be reduced and can even be transferred to other suppliers. To support the accuracy of the data, the company should record more detailed and real time so that the loss value can be calculated more optimally and more precisely.

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