The Integration of AHP and SAW Methods with Multiple Decision-Makers for Supplier Selection. A Case Study of UD BSA, Surabaya

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Abstract

Supplier selection is a decision-making process that considers many criteria. The industry has developed and implemented many Multi-criteria Decision-Making (MCDM) methods for supplier selection. The Analytic Hierarchy Process (AHP) method is one of the most widely used methods, however, the AHP method requires a lot of pairwise comparisons between criteria and alternatives, which will be more complex when there is interdependence between criteria and alternatives. In order to produce better decisions, the AHP method is often implemented with other methods like the Simple Additive Weighting (SAW) method. The SAW method applies simple calculations and does not require complicated computer programs. In previous studies, a single decision-maker carried out AHP and SAW together in the manufacturing industry. In this study, a decision-making method was developed by several decision-makers (DMs) by integrating the AHP and SAW methods. The results of integrating AHP and SAW with multiple decision-makers were tested at a wood trading company called UD BSA for supplier selection. In this study, 3 alternative suppliers were considered. The literature results and brainstorming with the company resulted in 5 criteria and 8 sub-criteria that were considered in selecting suppliers at UD BSA with 2 DMs: the owner as DM1 and experienced purchasing staff as DM 2. The DM weighting was determined by considering each DM's expertise in assessing the criteria and sub-criteria. The integration of the AHP and SAW methods with 2 DM produces the output weight of each DM and the calculation results of the supplier's assessment with the highest ranking. Based on the calculation results, DM2 has a higher weight of 56.13%, which means that DM 2 is more expert in assessing criteria and sub-criteria. In addition, the best-selected supplier is PP, with the highest overall score of 0.8354. From this case study, UD BSA designed a supplier ranking system, which the company can use if there are new suppliers or future supplier performance changes

Keywords
Supplier selection, Analytic Hierarchy Process (AHP), Simple Additive Weighting (SAW), Decision-make

1. Introduction
The use of several multi-criteria decision-making (MCDM) tools simultaneously has been widely used in decision-making. Two well-known tools are Analytical Hierarchy Process (AHP) and Simple Additive Weighting (SAW). These two tools have been used simultaneously in decision- making, for example, for the assessment of pharmaceutical supply chain risk in Iran (Jaberidoost et al. 2015), recommendation optimization (Kurniawati, Lenti, and Nugroho 2021), and supplier selection (Kumar et al. 2019).

In general, in previous studies, the use of several tools simultaneously was processed separately, and the decision-maker was carried out by one Decision-Maker (DM). However, in practice, decisions are often not made by one person but by more than one person. In cases with more than one DM, the decisions are often the result of compromise or voting.

Compromise or voting is a decision taken by ignoring the reality that among DMs, there are those whose knowledge or capabilities are better than other DMs. Realizing this, we need a tool that distinguishes the weight of DMs in making decisions. This study integrates AHP and SAW by considering more than one decision-maker, so-called group decision-making. This integration was applied to the supplier selection case. The AHP method was used in weighting the supplier selection criteria desired by the company as a consideration in determining the best supplier, where there were two decision-makers in the company and thereby called group decision making (GDM). Meanwhile, SAW is a weighted summation method for each alternative in all attributes.

Technological developments, globalization, increasingly varied customer demands, and increasingly competitive levels require companies to continue to develop themselves and have value added to compete in the industrial world. In addition to being known to the public, the company must be able to adapt to consumer expectations in quality, delivery accuracy, and flexibility in the number of appropriate products. This ideal condition can be achieved if the company's performance runs well and maximally. However the company is experiencing many problems that decrease its performance. One of the causes of the problem is the supplier who works with the company.

Suppliers play an essential role in ensuring the availability of raw materials in a manufacturing company. The delay in the supplier to the company will result in limited stock in the warehouse or even stock out, which will hamper sales transactions. One of the supporting factors for success in the procurement process is selecting the right supplier using the proper criteria (Taherdoost and Brad 2019). In this case, the company must choose the best supplier per the required criteria to minimize the risk of incompatibility with the supplier.

This article uses a ready-to-process wood trading company as a case study of the integration of AHP and SAW. The wood company was chosen as it has unique characteristics. The same type of wood may have varying qualities, influenced by the age of the tree when it was cut, the diameter of the tree from which the wood came from, the dryness of the wood, the wooden eye, and the area of origin of the wood may affect the quality of the wood because it is related to the climate in each region. Wood trading companies and buyers generally have different knowledge in recognizing wood quality, so problems between buyers and sellers are often triggered by quality problems in addition to price, delivery time, and other factors. UD Berkat Syukur Abadi is a trading company engaged in the wood sector. Currently, the company is collaborating with a supplier of Meranti wood located in Kalimantan. However, there are still some obstacles faced by the company, such as delays in delivery and wood quality. The company sees the wood quality from the size of the pieces of wood that are not following the requested, bent wood, rotten wood, and so on. The wood received by UD. Berkat Syukur Abadi is sold directly to customers, resulting in the company getting customer complaints. Several other suppliers sell the same product, but the decision-maker is often confused, so it is often too late to decide which supplier is the best. This is because the company is still focused on using intuition to make decisions and this intuition is often inaccurate in choosing suppliers.

1.1 Objectives

Therefore, the objectives of this study relate to selecting the best supplier from UD Berkat Syukur Abadi's several alternatives. In this study, the selection process was carried out by weighting the criteria and sub-criteria using the AHP method, considering group decision-making (GDM), and ranking alternative suppliers using the SAW method. In addition, a supplier ranking system design was designed to ease the company in selecting its supplier. This was done to anticipate changes in supplier performance or new suppliers in the future.

2. Literature Review

Supplier selection is a strategic activity, primarily if the supplier supplies critical goods that will be used in the long term. Various factors need to be considered in supplier selection. This can be very complex because the company has the ability in its field (Efraim Turban, Aronson, & Liang, 2005). Generally, many companies use basic criteria, including the quality of the goods offered, the purchase price, and the speed of time in delivery. However, when selecting their suppliers, companies are often required to consider more criteria (multi-criteria) that must be agreed upon by the supplier selection experts (Kellner, Lienland, and Utz 2019).

Multi-criteria decision-making with more than one decision-maker is known as Multi-Criteria Group Decision-Making (MCGDM). MCGDM has been widely used in supplier selection (Muralidharan, Anantharaman, and Deshmukh 2002) and (Huang et al. 2022). There are several elements of MCGDM, including alternatives, attributes/criteria, decision weights, decision matrices, and objectives (Yildiz and Yayla 2015).

In the application of MCGDM, decision-makers can use various methods to make preferences from existing criteria or alternatives, for example, in the form of preference orderings, utility value vectors, fuzzy preference relation (FPR), selected subset, fuzzy selected subset, normal preference relation, linguistic terms, and pairwise comparison

(Sreekumar & S, 2009). However, compared to other methods, FPR has an advantage in its aggregation. FPR is the presentation of information used in decision-making as a tool that collects the choices of a decision-maker into a group of decision-makers. The FPR is denoted as P in the alternative set X, which is a fuzzy set in the product X x X with the characteristic

$$\mu_p: X \times X \quad [0,1]$$

In this case, the preference matrix (Pk) is assumed to be additive reciprocity, namely Pji + Pij = 1 and Pii = 1/2 (F, F, & Viedma, 2001). Additive consistency produces three formulas for estimating Pik, among others, as follows:

$$\begin{aligned} ep_{ik}^{j1} &= p_{ij} + p_{jk} - \tfrac{1}{2}, \; j \neq i,k \\ ep_{ik}^{j2} &= p_{jk} - p_{ji} + \tfrac{1}{2}, \; j \neq i,k \\ ep_{ik}^{j3} &= p_{ij} - p_{kj} + \tfrac{1}{2}, \; j \neq i,k \end{aligned} \quad (1)$$

Figure 1. P_{ik} Estimation Formula P_{ik} (Herowati, 2019)

The DMs selected in the MCGDM have expertise in specific fields. The expertise of a decision-maker in a particular field is generally due to having a solid background in the field. Expertise refers to the ability to distinguish consistently, expressed as the CWS-Index as follows (Shanteau et al. 2002).

$$CWS\ Index = \frac{Discrimination}{Inconsistency} = \frac{\dfrac{\sum_{j=1}^{n} r(M_j - GM)^2}{n-1}}{\dfrac{\sum_{j=1}^{n}\sum_{i=1}^{r}(M_{ij} - M_j)^2}{n(r-1)}} \quad (2)$$

Where r is the number of replications, M_j is the average of individual scores for case j, GM is the grand mean of all individual values, n is the number of different cases, and M_{ij} is the individual value of i replications of case j. Using the CWS Index results, each decision-maker's weight will then be determined based on expertise. Expertise refers to the ability of a decision-maker to distinguish consistently.

Analytical Hierarchy Process (AHP)

The problem in the multi-criteria decision-making process is the weight determination for each criterion. Many methods have been developed to determine the weight of each criterion. The AHP is defined as a decision-making method that is widely used by users/managers in every company because this method is appropriate to be used in completing decision-making by compiling a hierarchical structure of elements, such as goals, criteria, sub-criteria, and alternatives (Saaty T., 2008).

AHP is a measurement theory used to find ratio scales through discrete or continuous pairwise comparisons. It is considered to be able to decompose complex multi-factor and multi-criteria problems into a hierarchy (Taherdoost 2017). Generally, decision-making in the AHP method is based on the following steps (Sangiorgio, Uva, and Fatiguso 2018):

1. Define the problem and determine the solution to be achieved.
2. Create a hierarchical structure that begins with the goal to be achieved, followed by the criteria and alternative choices that will be ranked.
3. Establish a pairwise comparison matrix that describes each element's relative contribution or influence on each goal or criterion at the top level. Comparisons are made based on the choice or judgment of the decision-maker by assigning a value to the level of importance of an element compared to other elements. The comparative value scale developed by Saaty (1980) is as follows.

Table 1 Pairwise Comparison Scale

Level of Importance	Definition	Explanation
1	Equal importance	Both elements have the same effect
3	Moderate importance of one element over another	An element is slightly favored one element over another
5	Strong importance of one element over another	An element is strongly favored
7	Very importance of one element over another	An element is very favored
9	Absolute important	An element is absolutely preferred over another, with high level of confidence
2,4,6,8	Intermediate values	The values between the two adjacent judgments
Reciprocal	Opposite	If element i has one of the above numbers when compared to element j, then element j is the opposite when compared to element I

4. Normalize the data by dividing the value of each element in the paired matrix by the total value of each column.
5. Calculate the eigenvector values and do consistency testing, where if it is not consistent then the data collection (preference) must be repeated. The eigenvector value in question is the maximum eigenvector value obtained using MATLAB or manually.
6. Repeat steps 3, 4, and 5 for all hierarchy levels.
7. Calculate the eigenvector of each pairwise comparison matrix. The eigenvector value is the weight of each element.
8. Test the consistency of the hierarchy. If CR < 0.100; then the assessment must be repeated.

The AHP method has been widely used for decision-making in various countries in various fields, including in supplier selection, with good results (Sandra, 2020); for instance, research by Widuri Wellya Sandra on the selection of cooking oil suppliers by considering five alternatives (Sandra, 2020).

Simple Additive Weighting (SAW)

The SAW method is the best-known and widely used method in dealing with Multiple Attribute Decision-making (MADM) situations. Compared with other decision-making models, the advantage of the SAW method is its ability to make a more precise assessment because it is based on predetermined criteria and preference weights. In addition, SAW can also select the best alternative from several available alternatives because there is a ranking process after determining the weight for each attribute (Prasad and Jaya 2019). The steps for completion using the SAW method are as follows (Trimulia, Defit, and Nurcahyo 2018):

1. Determine the criteria that will be used as a reference in decision-making, namely Ci.
2. Determine the suitable rating of each alternative on each criterion.
3. Decide matrix based on the criteria (Ci), then normalize the matrix based on the equation adjusted to the type of attribute (profit attribute or cost attribute) so that a normalized matrix R is obtained.

If j is a benefit attribute, then $Rij = \frac{Xij}{Max\ ij}$

If j is a cost attribute, then $Rij = \frac{Min\ ij}{X\ ij}$

4. The result is obtained through a rating process, namely the summation of the normalized matrix multiplication R with the weight vector so that the largest value is chosen as the best alternative (Ai)

$$Vi = \sum_{J=1}^{n} Wj\, rij \qquad (3)$$

Where V_i is the ranking for each alternative, W_j is the weighted value of each criterion, and dan R_{ij} is the normalized performance rating value**.**

3. Methods

This research is included in applied research, where research is designed to solve practical problems. The analysis used was descriptive analysis, using the Analytical Hierarchy Process (AHP) in group decision-making (GDM) and Simple Additive Weighting (SAW) methods. In this case, AHP was used as an instrument for determining the weight of each criterion and sub-criteria, and SAW was used as an instrument for determining priorities or rankings in determining the best supplier. The following Figure 1 is the thinking framework carried out in this research.

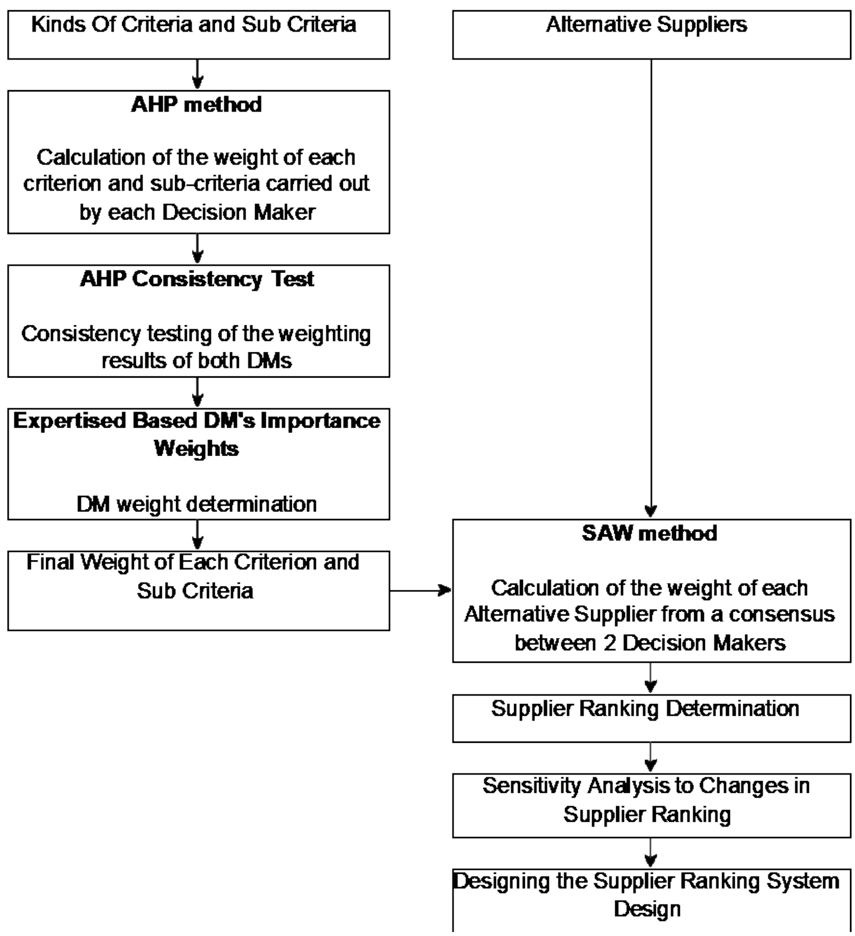

Figure 1. Thinking Framework

4. Data Collection and Result

AHP and SAW System Integration Design

The following is an overview of the system integration design of the two methods carried out in this study. (Figure 2)

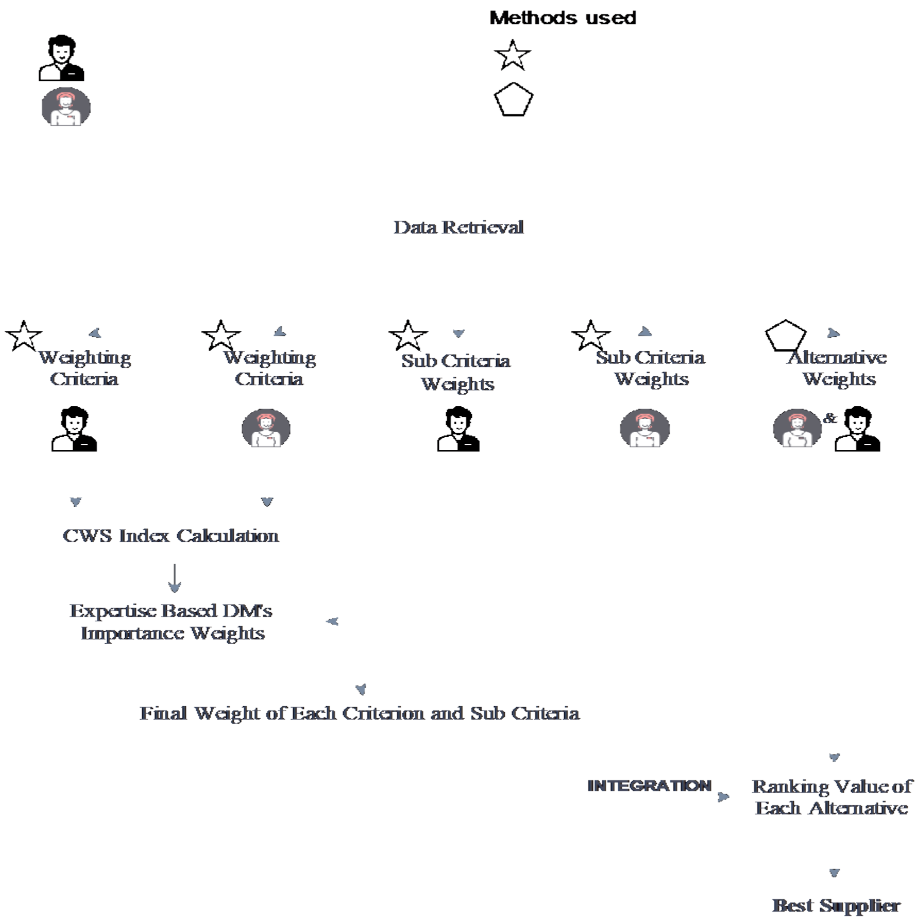

Figure 2. System Integration Design

Identifying Criteria and Sub Criteria

From the results of a literature review and brainstorming with the two decision-makers from UD Berkat Syukur Abadi, several criteria and sub-criteria in supplier selection have been considered, namely the cost criteria with the sub-criteria for price suitability and ease of payment, the quality criteria with the sub-criteria for product quality and quality consistency, the criteria for delivery with sub-criteria for delivery time and product suitability, and responsiveness criteria with sub-criteria for ease of communication and accuracy of completion, and flexibility criteria.(Table 2 & 3)

Weighting Using AHP

The two decision-makers weighted each criterion and sub-criteria using the Saaty scale on the AHP method, then tested the consistency of the weighting results. The consistency ratio (CR) results obtained for the weighting between criteria in DM 1 is 0.0696, and DM 2 is 0.0239. From these results, it can be concluded that the weighting between criteria carried out by the two DMs is consistent, because CR < 0.1. While the weighting between sub-criteria, because there are only 2 sub-criteria (matrix of order 2), then the value of the consistency index obtained is definitely <0.1, because the RI value for criteria 2 is 0.000, so the weighting between sub-criteria carried out by DM 1 and DM 2 has also been consistent. Furthermore, the weight calculation of each DM is carried out using the AHP completion step and the following results are obtained.

Table 2 Criteria Weight

Criterion	Decision-maker 1	Decision-maker 2
Cost	0.3364	0.3295
Quality	0.3364	0.3601
Delivery	0.2046	0.0881
Responsiveness	0.0904	0.1818
Flexibility	0.0322	0.0406

Table 3 Sub-Criteria Weight

Sub-Criteria	Decision-maker 1	Decision-maker 2
Price suitability	0.75	0.67
Ease of payment	0.25	0.33
Product quality	0.50	0.75
Quality consistency	0.50	0.25
Delivery time	0.25	0.20
Product suitability	0.75	0.80
Ease of Communication	0.13	0.50
Settlement Accuracy	0.88	0.50

Determining Decision-maker Weights

The weight of each decision-maker is not based on the organizational structure level but on his expertise in assessing the criteria and sub-criteria. Therefore, it is necessary to calculate the weight of each decision-maker to determine which DM has a greater influence in giving preference or weighting the criteria and sub-criteria. The calculation process using formula (1), (2), and (3) to calculate CWS index. After normalization of acculamulated log CWS index then, DMs important weights were found. The calculation results found that DM 2 had a greater weight value of 56.13%, while DM 1 was 43.87%. This signifies that DM 2, the company's administration, is more expert in assessing the criteria and sub-criteria than DM 1, namely the owner because the administration has a data recap of each supplier who has worked with the company. Hence, DM 2 has a greater influence on the weighing results.

Determining Final Weight of Criteria and Sub Criteria

The final weight results for each criterion in the supplier selection are obtained from the sum of the weights of each criterion or sub-criteria with the weights of each decision-maker (DM's Importance Weights). The following results are obtained.(Table 4 & 5)

Table 4 Criteria Final Weight

Criteria	Final Weight
Cost	0.3325
Quality	0.3497
Delivery	0.1392
Responsiveness	0.1417
Flexibility	0.0369

Table 5 Sub Criteria final weight

Sub-Criteria	Final Weight
Price suitability	0.7032
Ease of payment	0.2968
Product quality	0.6403
Quality consistency	0.3597
Delivery time	0.2219
Product suitability	0.7781
Ease of communication	0.3355
Settlement accuracy	0.6645

Determining Alternative Supplier Ranking

Supplier ranking was calculated using the SAW method. The first step was to group each criterion and sub-criteria based on the type of benefit or cost attribute as follows. (Table 6)

Table 6 Attribute Type Grouping

Criteria Code	Criteria	Sub-Criteria Code	Criteria / Sub-Criteria	Attribute type
C_1	Cost	SK_1	Price suitability	Cost
		SK_2	Ease of payment	Benefit
C_2	Quality	SK_3	Product quality	Benefit
		SK_4	Quality consistency	Benefit
C_3	Delivery	SK_5	Delivery time	Cost
		SK_6	Product suitability	Benefit
C_4	Responsiveness	SK_7	Ease of communication	Benefit
		SK_8	Settlement accuracy	Benefit
C_5	Flexibility	SK_9	Flexibility	Benefit

To ease reading the data, each alternative name was abbreviated as follows, A1 means alternative one, A2 means alternative two, and A3 means alternative three. Furthermore, the weighting between the criteria/sub-criteria with alternative suppliers was carried out based on the consensus between the two decision-makers to obtain the following results. (Table 7)

Table 7 Weighting using the SAW method

	SK_1	SK_2	SK_3	SK_4	SK_5	SK_6	SK_7	SK_8	SK_9
A_1	2	2	3	2	3	3	4	4	3
A_2	3	3	3	3	3	3	3	3	2
A_3	4	3	4	3	2	4	3	3	2

The next step was to normalize the matrix based on the type of attributes in each criterion and sub-criteria. The following is the result of normalizing the relationship matrix between criteria and sub-criteria with alternatives: (Table 8)

Table 8 Weighting matrix Normalization

R_{ij}	SK_1	SK_2	SK_3	SK_4	SK_5	SK_6	SK_7	SK_8	SK_9
A_1	1.00	0.67	0.75	0.67	0.67	0.75	1	1	1
A_2	0.67	1	0.75	1	0.67	0.75	0.75	0.75	0.67
A_3	0.50	1	1	1	1	1	0.75	0.75	0.67

Then the rating of each alternative is calculated as follows. (Table 9)

Table 9 Ranking Value Calculation Results for Each Alternative

	C_1	C_2	C_3	C_4	C_5	**Total V_i**
V_1	0.2996	0.2518	0.1018	0.1417	0.0369	**0.8318**
V_2	0.2546	0.2937	0.1018	0.1062	0.0246	**0.7810**
V_3	0.2156	0.3497	0.1392	0.1062	0.0246	**0.8354**

From the Ranking results, it can be concluded that V3 supplier has the highest-ranking value of 0.8354, so that V3 is the best supplier chosen to supply meranti wood from UD Berkat Syukur Abadi. Then in second place, namely V1 with a ranking value of 0.8318. Meanwhile, the supplier V2 occupies the last position with the lowest ranking value of 0.7810.

Sensitivity Analysis to Ranking Changes

Sensitivity analysis testing was carried out in order to find out changes in the ranking results of alternative suppliers obtained when changes are made to the weights of each decision-maker. The following are the results of the sensitivity analysis that has been carried out.

Table 10 Sensitivity Analysis Results

Weight		Supplier Alternative		
DM_1	DM_2	A_1	A_2	A_3
1.000	0.000	2	3	1
0.900	0.100	2	3	1
0.800	0.200	2	3	1
0.700	0.300	2	3	1
0.600	0.400	2	3	1
0.439	**0.561**	**2**	**3**	**1**
0.400	0.600	2	3	1
0.333	0.667	2	3	1
0.332	0.668	1	3	2
0.300	0.700	1	3	2
0.200	0.800	1	3	2
0.100	0.900	1	3	2
0.000	1.000	1	3	2

From the sensitivity analysis results above,(Table 10) it can be seen that a change in the rating of alternative suppliers occurs when the weight of decision-maker 2 is increased by 0.668 or 66.8% and the weight of decision-maker 1 is decreased by 0.332 or 33.2%. The ranking of alternative suppliers changed with V2 in the first position, followed by V3 in the second position. It can also be seen that V2 always ranks at the bottom, which means V2 is not the best supplier for UD Berkat Syukur Abadi and will not be selected even though there is a change in the weight of the decision-maker.

Supplier Ranking System Design

The system design was made to ease UD Berkat Syukur Abadi to determine the best supplier based on ranking using the Simple Additive Weighting (SAW) method according to the criteria and sub-criteria that have been carried out using the AHP method. In the future, the company can see changes in the performance of each supplier or new suppliers that the company can consider, so this system design is needed. In addition, the decision-making process in supplier selection is also faster and easier. The following is a design view of the supplier ranking system that has been designed using Microsoft Excel. (Figure 3)

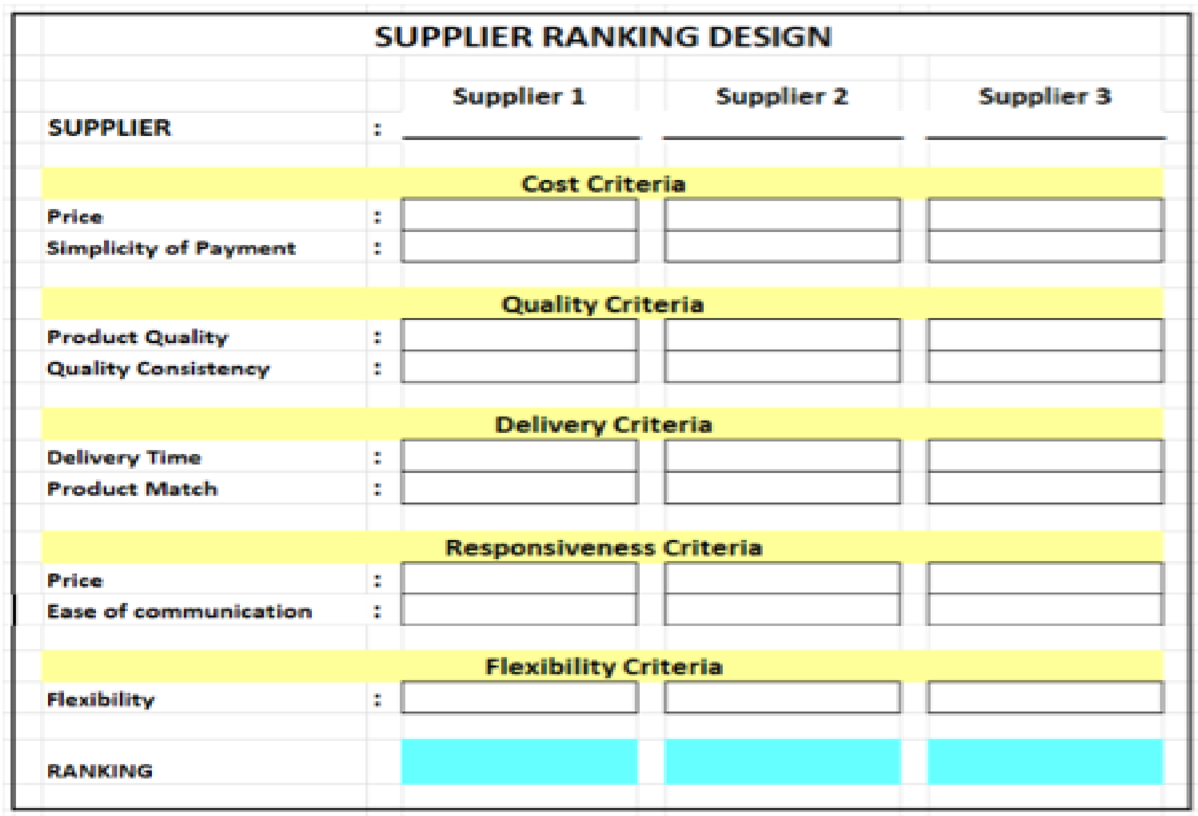

Figure 3. Display of supplier rating system design

5. **Conclusion**

The supplier ranking system design that has been designed by integrating AHP and SAW can facilitate and speed up the decision-making process of the two decision-makers in supplier selection.

Based on the results of the research that has been done, it is found two decision-makers from UD Berkat Syukur Abadi, namely DM1 and DM2 considered several criteria and sub-criteria in supplier selection, namely the cost criteria with the sub-criteria of price suitability and payment convenience; quality criteria with sub-criteria of product quality and quality consistency, delivery criteria with sub-criteria of delivery time and product suitability, responsiveness criteria with sub-criteria of ease of communication and accuracy of completion, and flexibility criteria. In addition, the results of the DM's Importance Weights calculation show that DM2, as the company's administration, has the largest weight, which signifies that DM2 is more expert in providing assessments on each of the existing criteria and sub-criteria.

The ranking of alternative suppliers found that the best supplier chosen to work with UD Berkat Syukur Abadi is the PP Supplier.

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