Selection of Suppliers by Weighted Aggregated Sum Product Assessment (WASPAS) Method

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Abstract Selection of an efficient supplier has always been a tough task in the arena of logistics management. The performance of a supplier depends on several factors that enables the researchers to consider this as a multi-criteria decision making (MCDM) problem. The goal of this research paper is to propose the most efficient supplier among 18 available alternatives on the basis of 5 performance criteria namely, price, distance, quality, supply variety and delivery performance by implementing analytic hierarchy process (AHP) to evaluate the criteria weights and weighted aggregated sum product assessment (WASPAS) to rank the alternatives. The results obtained shows that, supplier 10 and supplier 7 is the best and the worst choice, respectively among these 18 suppliers. On comparing with the previous researchers existing results executed by COPRAS and TOPSIS, it is observed that there are differences in the preference order of the alternatives, but the best and worst choice of suppliers remains same in all methods.

Keywords MCDM · AHP · Supplier selection · WAPAS

1 Introduction

Supplier selection problem now a days has become one of the core areas of interest for the decision maker (DM) to execute with the help of MCDM tools, as it involves several conflicting criteria for its efficient selection. Proper selection of a supplier is very much crucial for an engineering firm, as it is equally important with respect to other factors for the success of every industrial concern [1]. Lots of researchers successfully implemented different MCDM tools for the supplier selection in the last few years and some of the applications are stated as follows.

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Liu et al. [2] applied DEA for the supplier selection in a manufacturing firm. Shyur and Shih [3] developed a hybrid MCDM model of TOPSIS and ANP for deliberate vendor selection. Onut et al. [4] developed a supplier estimation approach in the GSM sector based on TOPSIS and ANP methods to help a Turkish telecommunication company under the fuzzy environment. Singh [5] evaluated and selected the most efficient supplier in fuzzy environment for television manufacturing organization using TOPSIS MCDM approach. Kilic [6] proposed an integrated approach of fuzzy-TOPSIS for choosing appropriate supplier in multi-supplier environment. Madic et al. [1] applied COPRAS method for estimating the performances of the suppliers. Murali et al. [7] analyzed a supplier selection problem by PROMETHEE and TOPSIS.

Nallusamy et al. [8] studied the applications of AHP, fuzzy logic and ANN for efficient supplier selection in manufacturing industries. Adali et al. [9] applied an alternative version of fuzzy-PROMETHEE for the selection of best supplier. Yazdani et al. [10] delivered a combined model for solving supplier selection problem using WASPAS, SWARA and QFD. Guchhait [11] solved a supplier evaluation problem by MOORA, SAW and TOPSIS method. Assellaou et al. [12] investigated a supplier selection problem of an African well-known refining company using a hybrid DEMATEL-ANP-TOPSIS methodology. Stojic et al. [13] implemented rough AHP to determine the weight coefficients of the criteria and rough WASPAS to rank the suppliers in a PVC producing company.

Bhakat and Raja [14] considered a case study of a Turkish textile company, where grey-AHP model is used for weighting the set of conflicting criteria and grey-WASPAS model for ordering the suppliers. Jayant et al. [15] presented a hybrid combination of WASPAS and MOORA MCDM procedures for vendor assessment and SWARA to evaluate the criteria weights in a battery manufacturing industry. Koganti et al. [16] proposed a MCDM model for supplier selection using GRA to pick out the proper criterions from existing options, AHP to determine the criteria weights and TOPSIS for the final selection process.

Apart from these, WASPAS technique is also applied in other areas like, Zavadskas et al. [17] presented a case study to rank the facades for commercial and public buildings by WPM, WSM, WASPAS and later it was examined by comparing to MOORA. Zavadskas et al. [18] applied WASPAS method for the assessment of alternative building designs and the robustness of the method is validated by applying MOORA and MULTIMOORA. Chakraborty and Zavadskas [19] explored eight manufacturing problems using WASPAS technique.

Karande et al. [20] investigated the ranking efficiency of six MCDM methods i.e. WASPAS, MOORA, MULTIMOORA, WPM and WSM using two industrial robot selection problems. Mathew and Sahu [21] solved two material handling equipment selection problem using 4 MCDM techniques i.e. WASPAS, EDAS, MOORA and CODAS. Badalpur and Nurbakhsh [22] considered an Iranian road construction project, where WASPAS is utilized for the risk assessment. Vinchurkar and Samtani [23] evaluated the performance of four different hydro-powerhouses by integrating SWARA for determining the criteria weights and WASPAS, TOPSIS, PROMETHEE to access the performance score of the alternatives.

From the above-mentioned literatures, it is clear that WASPAS method is very less utilized MCDM tool in the area of supplier selection and therefore needs to be explored more in-depth. Hence, WASPAS is adopted and applied to an existing supplier selection problem first presented by Liu et al. [2]. Later, it was further considered by Madic et al. [1] and evaluated using COPRAS method. In this paper, the criteria weights [1] and the decision matrix [1, 2] are taken from [1] and WASPAS is applied to fulfill the research gap. The output results are also compared with the previous researcher's outcomes which shows very minor differences among the ranking orders. Overall, solving a supplier selection problem with the help of WASPAS method for the first presents the novelty of this research work.

2 Materials and Methods

To start with the calculation procedure, firstly, it is required to determine the criteria weights which is done by using AHP [24]. The weights of the 5 criteria are taken from the article presented by Madic et al. [1] through AHP is as follows: $w_{\text{price}} = 0.1361$, $w_{\text{distance}} = 0.0438$, $w_{\text{quality}} = 0.4829$, $w_{\text{supply variety}} = 0.0782$, $w_{\text{delivery performance}} = 0.2591$. Now, starting with the WASPAS [25] method which is included under the Sect 2.1.

2.1 Weighted Aggregated Sum Product Assessment (WASPAS)

In WASPAS method, a joint generalized criterion shown by Eq. 7 was proposed by Zavadskas et al. [25] which combines WSM [26–28] and WPM [28, 29] together. According to Karande et al. (pp. 402–403) [20] 'it is applied for increasing ranking accuracy and it has the capability to reach the highest accuracy of estimation'. The WASPAS method steps are as follows.

Step 1: Create a performance evaluation matrix (decision matrix) having 'm' alternatives and 'n' criteria according to Eq. 1. The decision matrix as originally proposed by Liu et al. [2] is shown in Table 1.

$$D(m_i \times n_j)\begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{m1} & d_{m2} & \dots & d_{mn} \end{bmatrix} \tag{1}$$

where, $i = 1, 2\ldots, m; j = 1, 2\ldots, n$.

Step 2: Normalize the decision matrix by using Eqs. 2 or 3 according to the nature of the criteria.

Table 1 Performance matrix

Types	Min	Min	Max	Max	Max
	Price ($)	Distance (miles)	Quality (%)	Supply variety	Delivery performance (%)
S1	100	249	100	2	90
S2	100	643	99.79	13	80
S3	100	714	100	3	90
S4	100	1809	100	3	90
S5	100	238	99.83	24	90
S6	100	241	96.59	28	90
S7	100	1404	100	1	85
S8	100	984	100	24	97
S9	100	641	99.91	11	90
S10	100	588	97.54	53	100
S11	100	241	99.95	10	95
S12	100	567	99.85	7	98
S13	100	567	99.97	19	90
S14	100	967	91.89	12	90
S15	80	635	99.99	33	95
S16	100	795	100	2	95
S17	80	689	99.99	34	95
S18	100	913	99.36	9	85
Ideal value	80	238	100	53	100

Source Liu et al. [2]; Madic et al. [1]

$$\text{Maximum criteria, } N_{ij} = \frac{d_{ij}}{d_i^{\max}} \tag{2}$$

$$\text{Minimum criteria, } N_{ij} = \frac{d_i^{\min}}{d_{ij}} \tag{3}$$

where, $i = 1, 2\ldots, m; j = 1, 2\ldots, n$.

'$d_i^{\max}$' and '$d_i^{\min}$' are the maximum and the minimum values of the ith criteria respectively. Table 2 shows the normalized decision matrix.

Step 3: Now calculate the weighted sum (WS_i) of each alternative using Eq. 4. The weighted sum is determined for all the alternatives and shown in Table 3.

$$\text{WS}_i = \sum_{j=1}^{n} N_{ij} w_j \tag{4}$$

where, $i = 1, 2\ldots, m; j = 1, 2\ldots, n$.

Table 2 Normalized matrix

	Price ($)	Distance (miles)	Quality (%)	Supply variety	Delivery performance (%)
Weights	0.1361	0.0438	0.4829	0.0782	0.2591
S1	0.8	0.9558	1	0.0377	0.9
S2	0.8	0.3701	0.9979	0.2453	0.8
S3	0.8	0.3333	1	0.0566	0.9
S4	0.8	0.1316	1	0.0566	0.9
S5	0.8	1	0.9983	0.4528	0.9
S6	0.8	0.9876	0.9659	0.5283	0.9
S7	0.8	0.1695	1	0.0189	0.85
S8	0.8	0.2419	1	0.4528	0.97
S9	0.8	0.3713	0.9991	0.2075	0.9
S10	0.8	0.4048	0.9754	1	1
S11	0.8	0.9876	0.9995	0.1887	0.95
S12	0.8	0.4198	0.9985	0.1321	0.98
S13	0.8	0.4198	0.9997	0.3585	0.9
S14	0.8	0.2461	0.9189	0.2264	0.9
S15	1	0.3748	0.9999	0.6226	0.95
S16	0.8	0.2994	1	0.0377	0.95
S17	1	0.3454	0.9999	0.6415	0.95
S18	0.8	0.2607	0.9936	0.1698	0.85

Source Author himself

'N_{ij}' is the normalized value of the ith alternative and jth criteria, 'w_j' is the weight of the jth criteria and 'WS_i' is the weighted sum of the ith alternative.

Step 4: Now calculate the weighted product (WP_i) of each alternative using Eq. 5. The weighted product is determined for all the alternatives and shown in Table 4.

$$WP_i = \prod_{j=1}^{n} N_{ij}^{w_j} \tag{5}$$

where, $i = 1, 2\ldots, m; j = 1, 2\ldots, n$.

'N_{ij}' is the normalized value of the ith alternative and jth criteria, 'w_j' is the weight of the jth criteria and 'WP_i' is the weighted product of the ith alternative.

Step 5: Now determine the joint generalized criterion (Q_i) of each alternative by using Eq. 6 [17, 18].

Table 3 Weighted sum of the alternatives

	Price ($)	Distance (miles)	Quality (%)	Supply variety	Delivery performance (%)	Weighted sum (WS_i)
S1	0.1089	0.0419	0.4829	0.0030	0.2332	0.8698
S2	0.1089	0.0162	0.4819	0.0192	0.2073	0.8334
S3	0.1089	0.0146	0.4829	0.0044	0.2332	0.8440
S4	0.1089	0.0058	0.4829	0.0044	0.2332	0.8352
S5	0.1089	0.0438	0.4821	0.0354	0.2332	0.9034
S6	0.1089	0.0433	0.4664	0.0413	0.2332	0.8931
S7	0.1089	0.0074	0.4829	0.0015	0.2202	0.8209
S8	0.1089	0.0106	0.4829	0.0354	0.2513	0.8891
S9	0.1089	0.0163	0.4825	0.0162	0.2332	0.8570
S10	0.1089	0.0177	0.4710	0.0782	0.2591	0.9349
S11	0.1089	0.0433	0.4827	0.0148	0.2461	0.8957
S12	0.1089	0.0184	0.4822	0.0103	0.2539	0.8737
S13	0.1089	0.0184	0.4828	0.0280	0.2332	0.8712
S14	0.1089	0.0108	0.4437	0.0177	0.2332	0.8143
S15	0.1361	0.0164	0.4829	0.0487	0.2461	0.9302
S16	0.1089	0.0131	0.4829	0.0030	0.2461	0.8540
S17	0.1361	0.0151	0.4829	0.0502	0.2461	0.9304
S18	0.1089	0.0114	0.4798	0.0133	0.2202	0.8336

Source Author himself

$$Q_i = 0.5(\mathrm{WS}_i) + 0.5(\mathrm{WP}_i) = 0.5\sum_{j=1}^{n} N_{ij}w_j + 0.5\prod_{j=1}^{n} N_{ij}^{w_j} \quad (6)$$

where, $i = 1, 2\ldots, m; j = 1, 2\ldots, n$ and 'Q_i' is the joint criterion of the ith alternatives.

Saparauskas et al. [30] and Zavadskas et al. [25] proposed a more generalized formula to increase the effectiveness and the ranking accuracy of the method [19] which is shown by Eq. 7.

$$Q_i = \lambda(\mathrm{WS}_i) + (1-\lambda)(\mathrm{WP}_i) = \lambda\sum_{j=1}^{n} N_{ij}w_j + (1-\lambda)\prod_{j=1}^{n} N_{ij}^{w_j} \quad (7)$$

where, $i = 1, 2\ldots, m; j = 1, 2\ldots, n$.

'λ' is a constant and its values ranges from 0 to 1. $\lambda = 0, 0.1, 0.2, 0.3\ldots, 1$.

Table 4 Weighted product of the alternatives

	Price ($)	Distance (miles)	Quality (%)	Supply variety	Delivery performance (%)	Weighted product (WP_i)
S1	0.9701	0.9980	1	0.7739	0.9731	0.7291
S2	0.9701	0.9574	0.9990	0.8959	0.9438	0.7846
S3	0.9701	0.9530	1	0.7989	0.9731	0.7187
S4	0.9701	0.9150	1	0.7989	0.9731	0.6900
S5	0.9701	1	0.9992	0.9399	0.9731	0.8865
S6	0.9701	0.9995	0.9834	0.9513	0.9731	0.8826
S7	0.9701	0.9252	1	0.7331	0.9588	0.6308
S8	0.9701	0.9397	1	0.9399	0.9921	0.8501
S9	0.9701	0.9575	0.9996	0.8843	0.9731	0.7989
S10	0.9701	0.9612	0.9880	1	1	0.9213
S11	0.9701	0.9995	0.9998	0.8777	0.9868	0.8396
S12	0.9701	0.9627	0.9993	0.8536	0.9948	0.7924
S13	0.9701	0.9627	0.9999	0.9229	0.9731	0.8386
S14	0.9701	0.9404	0.9600	0.8903	0.9731	0.7588
S15	1	0.9579	1	0.9636	0.9868	0.9109
S16	0.9701	0.9485	1	0.7739	0.9868	0.7027
S17	1	0.9545	1	0.9659	0.9868	0.9097
S18	0.9701	0.9428	0.9969	0.8705	0.9588	0.7610

Source Author himself

From the Eqs. 6 and 7 it can be observed that, if the value of λ is 0 then the first part gets eliminated and it is converted into WPM and if λ is 1 then it is converted into WSM [19, 20].

The joint generalized criterion (Q_i) of each alternative is calculated for every λ values using Eq. 7 and shown in Table 5.

3 Results and Discussion

This section includes the outcome results and ranking of the supplier. Table 5 shows the joint generalized criteria of the 18 alternatives for every λ values. Now the supplier with the highest Q_i value is termed as the best one and the ranking is proposed according to the decreasing Q_i values. However, 11 alternative rankings can be made for the eleven individual cases which are depicted in Table 6.

From Table 6, the variations in the rankings can be observed for different λ values and it can also be noted that the best choice supplier is same for all the λ values. However, it is recommended to consider the ranking for $\lambda = 0.5$ as the final ranking by

Table 5 Joint criterion of each alternative for different ‘λ’ values

	λ = 0	λ = 0.1	λ = 0.2	λ = 0.3	λ = 0.4	λ = 0.5	λ = 0.6	λ = 0.7	λ = 0.8	λ = 0.9	λ = 1
S1	0.7291	0.7432	0.7573	0.7713	0.7854	0.7995	0.8135	0.8276	0.8417	0.8557	0.8698
S2	0.7846	0.7894	0.7943	0.7992	0.8041	0.8090	0.8139	0.8188	0.8237	0.8286	0.8334
S3	0.7187	0.7312	0.7437	0.7563	0.7688	0.7813	0.7939	0.8064	0.8189	0.8315	0.8440
S4	0.6900	0.7045	0.7190	0.7335	0.7481	0.7626	0.7771	0.7916	0.8061	0.8206	0.8352
S5	0.8865	0.8882	0.8899	0.8916	0.8933	0.8949	0.8966	0.8983	0.9000	0.9017	0.9034
S6	0.8826	0.8837	0.8847	0.8857	0.8868	0.8878	0.8889	0.8899	0.8910	0.8920	0.8931
S7	0.6308	0.6499	0.6689	0.6879	0.7069	0.7259	0.7449	0.7639	0.7829	0.8019	0.8209
S8	0.8501	0.8540	0.8579	0.8618	0.8657	0.8696	0.8735	0.8774	0.8813	0.8852	0.8891
S9	0.7989	0.8048	0.8106	0.8164	0.8222	0.8280	0.8338	0.8396	0.8454	0.8512	0.8570
S10	0.9213	0.9226	0.9240	0.9254	0.9267	0.9281	0.9295	0.9308	0.9322	0.9336	0.9349
S11	0.8396	0.8452	0.8508	0.8564	0.8620	0.8676	0.8732	0.8789	0.8845	0.8901	0.8957
S12	0.7924	0.8006	0.8087	0.8168	0.8249	0.8331	0.8412	0.8493	0.8574	0.8656	0.8737
S13	0.8386	0.8418	0.8451	0.8484	0.8516	0.8549	0.8582	0.8614	0.8647	0.8680	0.8712
S14	0.7588	0.7643	0.7699	0.7754	0.7810	0.7865	0.7921	0.7976	0.8032	0.8087	0.8143
S15	0.9109	0.9128	0.9147	0.9167	0.9186	0.9205	0.9225	0.9244	0.9263	0.9283	0.9302
S16	0.7027	0.7179	0.7330	0.7481	0.7632	0.7784	0.7935	0.8086	0.8237	0.8389	0.8540
S17	0.9097	0.9118	0.9139	0.9159	0.9180	0.9201	0.9221	0.9242	0.9263	0.9283	0.9304
S18	0.7610	0.7683	0.7755	0.7828	0.7900	0.7973	0.8046	0.8118	0.8191	0.8264	0.8336

Source Author himself

WASPAS [19] since, equal priority should be given to both WSM and WPM methods. Table 7 shows the ranking comparisons of the suppliers by COPRAS, TOPSIS and WASPAS method and Fig. 1 represents the ranking comparisons graphically. A final ranking of the suppliers is also proposed following Copeland voting method which is also provided in Table 7. Spearman rank correlation coefficient among the three rankings obtained from three different methods are also given in Table 8. The final ranking obtained from this analysis is as follows.

S10 > S17 > S15 > S6 > S5 > S8 > S13 > S11 > S12 > S9 > S2 > S1 > S18 > S16 > S14 > S3 > S4 > S7

From Table 8, it can be observed that the proposed rankings hold a good Spearman rank correlation coefficient among each other and there are not many differences in the ranking orders as depicted in Table 7. So, it is quite tough to judge and give opinion about the best one among them. But, if we notice the rank coefficient between the final ranking and the other methods, then it is clear that TOPSIS and WASPAS are coming out with the highest coefficient, i.e., 0.98762, which is enough to consider these two methods as the most robust and gives more accurate results compared to COPRAS.

Table 6 Ranking of the alternatives for different λ values

	λ = 0	λ = 0.1	λ = 0.2	λ = 0.3	λ = 0.4	λ = 0.5	λ = 0.6	λ = 0.7	λ = 0.8	λ = 0.9	λ = 1
S1	14	14	14	14	13	12	12	11	11	10	10
S2	11	11	11	11	11	11	11	12	13	14	16
S3	15	15	15	15	15	15	14	15	15	13	13
S4	17	17	17	17	17	17	17	17	16	16	14
S5	4	4	4	4	4	4	4	4	4	4	4
S6	5	5	5	5	5	5	5	5	5	5	6
S7	18	18	18	18	18	18	18	18	18	18	17
S8	6	6	6	6	6	6	6	7	7	7	7
S9	9	9	9	10	10	10	10	10	10	11	11
S10	1	1	1	1	1	1	1	1	1	1	1
S11	7	7	7	7	7	7	7	6	6	6	5
S12	10	10	10	9	9	9	9	9	9	9	8
S13	8	8	8	8	8	8	8	8	8	8	9
S14	13	13	13	13	14	14	16	16	17	17	18
S15	2	2	2	2	2	2	2	2	2	3	3
S16	16	16	16	16	16	16	15	14	12	12	12
S17	3	3	3	3	3	3	3	3	3	2	2
S18	12	12	12	12	12	13	13	13	14	15	15

Source Author himself

4 Conclusion

It can be concluded from the above analysis that supplier 10 is the best option and supplier 7 is the worst choice among these 18 available alternatives. WASPAS is more effective method than WPM and WSM alone, as it gives priority and combines the advantages of both methods and provides more accurate results when λ = 0.5. Although, the best and the worst supplier choices are exactly same for all the three methods but there are some variations in the preference ranking order which are justified by the rank coefficient. However, the three rankings show very minor differences in their order. Although, TOPSIS and WASPAS proved to be the most robust techniques, but COPRAS also competed equally and lags behind by an inch.

The same analysis can also be carried out by employing other MCDM tools like PROMETHEE, VIKOR, ELECTRE, etc., and the rankings can be compared to these. For solving supplier selection problems, there are others factors like, past experiences, service and warranty, transportation cost, behavior, etc., can also be considered along with these to make the selection process more precise and accurate.

Table 7 Ranking comparisons by TOPSIS, COPRAS and WASPAS

	TOPSIS	COPRAS	WASPAS	Final rank
S1	12	17	12	12
S2	11	11	11	11
S3	15	15	15	16
S4	17	16	17	17
S5	5	6	4	5
S6	4	5	5	4
S7	18	18	18	18
S8	6	4	6	6
S9	10	10	10	10
S10	1	1	1	1
S11	8	8	7	8
S12	9	9	9	9
S13	7	7	8	7
S14	14	14	14	15
S15	3	3	2	3
S16	13	13	16	14
S17	2	2	3	2
S18	16	12	13	13

Source Madic et al. [1]; Author himself

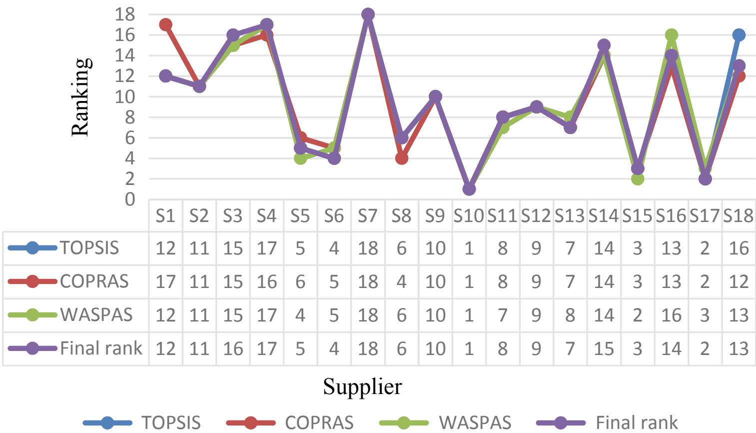

Fig. 1 Graphical comparison of different proposed rankings. *Source* Madic et al. [1]; Author himself; Created by Microsoft chart option

Table 8 Spearman rank correlation co-efficient among different proposed rankings

	WASPAS	TOPSIS	COPRAS	Final rank
WASPAS	–	0.97523	0.95046	0.98762
TOPSIS		–	0.95046	0.98762
COPRAS			–	0.96285
Final rank				–

Source Author himself

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