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Integration of Data Envelopment Analysis with Analytical Hierarchy Process and Entropy Measurement in the Optimization of Supplier Selection

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Abstract Supplier selection is perceived as important decision-making process in any supply chain management. In this study, the best supplier for a company is being determined based on five main criteria chosen which are delivery, capacity, warranty, cost, and quality. The Analytic Hierarchy Process (AHP) and Entropy Measurement (EM) methods are integrated with Data Envelopment Analysis (DEA) was applied to set ranking and choose the best supplier as conventional DEA is not able to provide complete ranking among inefficient units. The mathematical modelling is executed using LINGO software. Supplier 3 has obtained efficient result of score 1 for both hybrid method and in Super Efficiency method as the most efficient supplier. Then, the results are validated using Spearman's Rank Correlation Coefficient (SRCC) which shows positive correlation between both integrated methods. Finally, findings of this study indicate the feasibility of integrated AHP-DEA and EM-DEA for supplier selection with multiple criteria.

Keywords Analytic Hierarchy Process; Data Envelopment Analysis; Entropy Measurement; Supplier Selection

Mathematics Subject Classification

1 Introduction

Increments and assortments of customer demands, advances of ongoing innovations in information systems and high environmental awareness have driven business to concentrate on supply chain management as according to Kilincci et al. [1]. Supplier selection is one of the mechanisms in supply chain management by which companies distinguish, analyze, and negotiate with suppliers.

The selection of the suppliers plays a significant part in the overall and success of any organization. The primary goals of the supplier selection process are to deliver quality product at a reasonable cost, minimize the risk of the purchase, increase the net benefit to the purchaser, and create closeness and long-term partnerships between purchasers and suppliers, as discussed in Taherdoost and Brard [2]. Besides, supplier selection is a multi-criteria problem that incorporates both qualitative and quantitative factors where it is necessary to make a compromise between tangible and intangible factors that some of which may conflict to select the right suppliers [1]. This process can be regarded as multiple-criteria decision making (MCDM) process which aims to evaluate several numbers of suppliers with a set of common criteria, as explained by Rashid et al. [3]. Pitchipoo et al. [4] revealed that there are many MCDM methods that have been proposed such as data envelopment analysis, analytic hierarchy process, analytic network process, genetic algorithm, preference ranking organization method for enrichment evaluation, case-based reasoning and fuzzy set theory.

According to Mahad et al. [5], DEA is a non-parametric method that has become an influential approach in measuring the efficiency of a set of comparable entities known as decision making units (DMUs). Efficiency analysis is vital for the evaluation of supplier selection performance, in which the DEA will be used as a data-oriented method to evaluate the efficiency of a set of DMUs. The DEA manages to convert several inputs into several outputs that are measured in different units. Specifically, Charnes et al. [6] explained that, the application of DEA requires solving a separate linear program for each DMUs and it is a non-parametric method where the assumption of normal distribution relating to inputs and outputs are not required for this method. It has also been applied across a wide range of many industries such as evaluation efficiency of water provider in Norbaizura et al. [7], public state libraries in Guccio et al. [8], banking sector in Othman et al. [9] and sustainable supplier evaluation in Zarbakhshnia et al. [10]. However, the standard DEA can only classify DMUs as efficient or inefficient unit where this method cannot discriminate against efficient DMUs. Complete ranking among the efficient unit is not possible even though ranking DMUs is important for decision making process as discussed in Starcevic et al. [11].

AHP is a measurement theory that depends on the values and judgments of individuals and groups which capture both subjective and objective evaluation criteria in term of providing a useful mechanism for checking the consistency of the evaluation criteria and alternatives recommended by the team to reduce bias in the decision-making process [4]. A fundamental scale is used to convert the decision maker's preferences into numerical weight. The scale of numbers indicates how significant one element to another when the it is compared pairwise explains in Saaty [12]. The AHP has been used widely in many fields of life due to its simplicity and flexibility as in the field of finances in Jihadi et al. [13], engineering in Azadeh et al. [14], education in Wang et al. [15] and production in Roosta et al. [16]. Entropy measurement (EM) is a measurement of the uncertainty which represented by a discrete probability distribution. If the entropy value is high, it indicates high uncertainty contained in the criterion, low diversification of the information and less criterion influence [4]. Both AHP and EM can be used to determine the weight for criteria as well as providing complete ranking among the efficient units. Therefore, the focus of this study is to choose and set the rank for the appropriate supplier for an apparel company which will be determine through the integration methods of AHP-DEA and EM-DEA based on five criteria which are cost, delivery, capacity, quality and warranty. Finally, the validation of the integrated model is determined by using Spearman's Rank Correlation Coefficient (SRCC) to find the correlation between the results obtained from both integrated methods.

2 Methodology

2.1 Model Development

Figure 1 shows the steps in methodology for the efficiency measurement for supplier selection of an apparel company which employ the application of hybrid method of AHP-DEA and EM-DEA models as referred to Pitchipoo et al. [4].

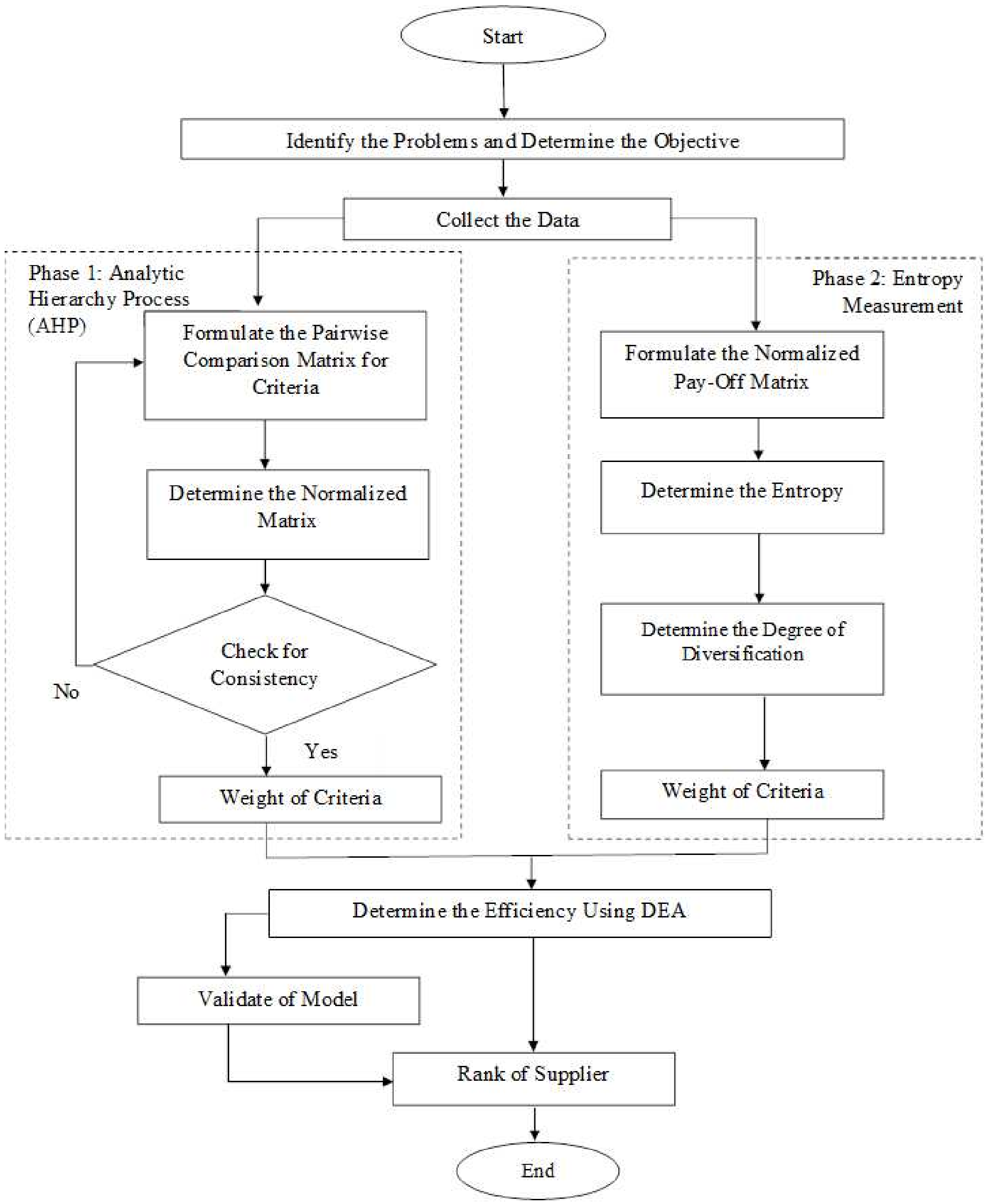

Figure 1: Proposed Framework

2.2 Collection of Data

The data for this study are collected from an apparel company located in Kuala Lumpur, Malaysia that produce corporate clothes. The suppliers of the raw materials should be selected appropriately in order to ensure the quality of the products and the company could remain competitive in the market. Previously, the company would select their suppliers using past experience as well as using bidding technique based on cost without taking into account the quality, defect item and other criteria. There is also no specific quantitative analysis is being conducted to assess the performance of the suppliers. Thus, this study will concentrate on performance evaluation and supplier selection involving five criteria, delivery (D) in days, capacity (Ca) in units, warranty (W) in a number of days, cost (C) in Ringgit Malaysia (RM), and quality (Q) in the percentage of acceptance as referred to [4]. The delivery, capacity, and warranty are chosen as inputs while cost and quality in the percentage of acceptance are considered as the output. The data were collected from five suppliers which previously has been involved with the company with five criteria are shown in Table 1. The weight of those criteria is executed by AHP and entropy measurement and further efficiency measurement for the five suppliers are determined by DEA from the resulted weights.

Table 1: Dataset of Inputs and Outputs

Suppliers	Inputs			Outputs	
	Delivery (D) in days	Capacity (Ca) in units	Warranty (W) in days	Cost (C) in RM	Quality (Q) in percentage of acceptance
Supplier 1	14	100	60	450	0.6
Supplier 2	5	200	365	800	0.9
Supplier 3	7	300	365	9000	0.83
Supplier 4	3	100	240	480	0.76
Supplier 5	3	500	365	3750	0.95

2.3 Determination of Weights Using AHP Method

The AHP is utilized to calculate the weights of the criteria of the suppliers. This method was introduced by Saaty [12], where AHP is an overall estimation hypothesis or measurement theory which combine both subjective and objectives assessment criteria that relies upon judgements of individuals and groups. This method also gives a valuable component to check the consistency of the assessment criteria and options suggested by the group hence decreasing favoritism in the decision-making process [4]. The basic scale which is utilized to convert the decision maker's preferences into numerical weight is shown in Table 2 proposed by Saaty [12].

The AHP procedure begins with the formulation of pairwise comparison matrix called criteria matrix (X_{att}) which is formed by contrasting every criterion with others. All the cell values are allocated by depending on the significance of the criteria earned from the administrator's management who act as the decision makers in the organization. The whole process of calculating the weight through AHP method is described as proposed by Pitchipoo et. al [4].

Table 2: Measurement Scale for Pairwise Comparison

Preference	Numerical Rating
Extremely preferred	1
Very strongly to extremely preferred	2
Very strongly preferred	3
Strongly to very strongly preferred	4
Strongly preferred	5
Moderately to strongly preferred	6
Moderately preferred	7
Equally to moderately preferred	8
Equally preferred	9

Step 1: Establish the pairwise comparison structure,

$$X_{\text{att}} = \left[a_{\text{ij}}\right] \;;\; \text{X}_{\text{att}} = 1 \leq \text{i}, \text{j} \leq m, \tag{1}$$

where,
a_{ij}= Pair wise comparison of i^{th} and j^{th} attribute
m = the number of alternatives

$$X_{\text{att}} = \begin{bmatrix} 1 & a_{12} & .....\text{a}_{1\text{m}} \\ 1/\text{a}_{12} & 1 & .....\text{a}_{2\text{m}} \\ \dots & \dots & .... \\ 1/\text{a}_{1\text{m}} & 1/\text{a}_{2\text{m}} & ...1 \end{bmatrix}.$$

Step 2: The criteria matrix is normalized using equation (2) and the normalized matrix, N_{att} is obtained.

$$N_{\text{ij}} = \frac{a_{\text{ij}}}{T_j}, \tag{2}$$

where $T_j = \sum_{i=1}^{m} a_{\text{ij}}$, $1 \leq j \leq m$

$$N_{\text{att}} = \begin{bmatrix} N_{11} & N_{12} & N_{13} & N_{14} & ... & \text{N}_{1\text{m}} \\ N_{21} & N_{22} & N_{23} & N_{24} & ... & \text{N}_{2\text{m}} \\ N_{31} & N_{32} & N_{33} & N_{34} & ... & \text{N}_{3\text{m}} \\ \vdots & \vdots & \vdots & \vdots & & \vdots \\ \vdots & \vdots & \vdots & \vdots & & \vdots \\ N_{\text{m}1} & N_{\text{m}2} & N_{\text{m}3} & N_{\text{m}4} & ... & \text{N}_{\text{mm}} \end{bmatrix}.$$

Step 3: Next the weights, W_{att} are computed from the normalized matrix:

$$W_{\text{att}} = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ \vdots \\ w_n \end{bmatrix}, \tag{3}$$

where $w_i = \frac{\sum_{j=1}^{m} N_{\text{ij}}}{m}$.

Step 4: Check the Consistency Ratio, CR of the proposed pairwise comparison matrix using equation (4) where the Random Index, RI is shown in Table 3.

$$\text{Consistency Ratio (CR)} = \frac{\text{CI}}{\text{CR}} \tag{4}$$

Table 3: Comparison Random Indexes (RI)

M	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.90	1.12	1.24	1.33	1.39	1.45	1.49	1.51	1.54

Table 3 shows the Random Indexes (RI) for various matrix sizes, m, that have been approximated earlier. The judgement is consistent if CR is less than 0.10 [12].

The consistency index, CI can be expressed as equation (5) and let λ_{max} be the maximum eigenvector and m is the size of the matrix.

$$\text{CI}=\frac{\lambda_{\text{max}} - m}{m - 1}. \tag{5}$$

2.4 Determination of Weights Using Entropy Measurement

The EM is a measure of the uncertainty which is represented by a discrete probability distribution. This approach is independent of the decision maker's viewpoints where the determines of the weights of the various criteria come from the pay-off matrix. The concept is based on the amount of information available and used to explore the contrast and difference between the sets of data as discussed in Ching and Kwangsun [17]. The first step started by preparing the normalized pay-off matrix based on a dataset of inputs and outputs as shown in Table 1. the rest of the process of calculating the weight through EM is as in Equation (9) to (10) by Pitchipoo et al. [4].

$$P_{\text{ij}} = \begin{bmatrix} N_{11} & N_{21} & \ldots & \ldots & N_{1\text{n}} \\ N_{21} & N_{12} & \ldots & \ldots & N_{2\text{n}} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ N_{\text{m}1} & N_{\text{m}2} & \ldots & \ldots & N_{\text{mn}} \end{bmatrix},$$

where,

$$N = \frac{X_{\text{ij}}}{\sum_{i=1}^{m} X_{\text{ij}}}, \tag{6}$$

$x_i(j) = j^{th}$ criteria value for i^{th} alternative

Next, matrix P_{ij} is used to determine the entropy value of each criterion by using the equation (7) as shown below.

$$E_j = \frac{-1}{ln(m)} \sum_{i=1}^{m} p_{ij} ln(p_{ij}), \tag{7}$$

where m is the number of alternatives.

The degree of diversification of the information provided by the criterion's outcomes is then determined as follows:

$$D_j = 1 - E_j. \tag{8}$$

Lastly, the result from (8) is used to calculate the criteria's weights,

$$W_i(j) = \frac{D_j}{\sum_{j=1}^{n} D_j}. \tag{9}$$

2.5 Data Envelopment Analysis (DEA)

The DEA is a nonparametric method in operational research used for assessing the relative efficiency of homogeneous Decision-Making Units (DMUs) which convert multiple inputs into multiple outputs which does not need a presumption of typical dissemination related to inputs and outputs [6]. DEA also able to handle those two groups of factors which are the input and output even there are in different unit. The DEA provides the efficiency score for each of the DMU with the range between 0 to 1 where less productive units or inefficiency are identified with efficiency score that is less than 1. The utilization of DEA requires a different linear program for every DMU. This model is designed to evaluate the relative performance of some decision making DMU which is, designated as DMU_o, based on observed performance of $j = 1, 2, \ldots, n$ DMUs. The DMU is to be regarded to be the entity which is responsible for converting inputs into outputs. The fundamental efficiency and proficiency measurement that is utilized in DEA is the ratio of overall outputs to the overall inputs and the model which was developed by Charnes et al. [6] is given below:

Maximize:

$$h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}}. \tag{10}$$

Subject to:

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1$$

$$v_i, u_r \geq \varepsilon \text{ for all } i, r$$

where,
$i = 1, 2, 3\ldots, m$ are inputs
$r = 1, 2, 3\ldots, s$ are outputs
$j = 1, 2, 3\ldots, n$ are DMU's
u_r = the weight assigned to the r^{th} output
v_i = the weight assigned to the i^{th} input
y_{rj} = amount of the r^{th} output for the j^{th} DMU
X_{ij} = amount of the i^{th} input for the j^{th} DMU

If $h_o = 1$, it means that DMU is efficient relative to other units, otherwise it is inefficient.

The very first DEA model was proposed by Charnes et. al [6], where it is called after their initials as a CCR model. The CCR is the Constant Scale Returns (CRS) radial model where CCR model can be categorized into two model which are input-oriented CCR model and output-oriented CCR model. Input-oriented CCR model is aimed to minimize the inputs used by maintaining the output produced while output-oriented CCR model focused on maximizing output produced by maintaining the input used [7]. The primal model of CCR input oriented model will be applied in this study and LINGO software will be used to execute the mathematical model. Supposedly, there are n DMUs where each DMU$_j$ (j = 1,2,3..., n) utilizes m inputs and s outputs where the formula is illustrated as below by Pitchipoo et al. [4].
Maximize

$$\theta_\circ = \sum_{r=1}^{s} u_r y_{r0}. \tag{11}$$

Subject to:

$$\sum_{i=1}^{m} v_i x_{i1} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad j = 1, \ldots, n$$

$$u_r, v_i \geq \varepsilon \text{ for all } r \text{ and } i,$$

where,
$i = 1, 2, 3\ldots,m$ are inputs
$r = 1, 2, 3\ldots,s$ are outputs
$j = 1, 2, 3\ldots,n$ are DMU's
u_r = the weight assigned to the r^{th} output
v_i = the weight assigned to the i^{th} input
y_{rj} = amount of the r^{th} output for the j^{th} DMU
X_{ij} = amount of the i^{th} input for the j^{th} DMU

If $\theta_o = 1$, it means that DMU is efficient relative to other units, otherwise it is inefficient.

2.6 Super Efficiency DEA Model

The best performance of a DMU is reflected by an efficiency score of one in various DEA models. This efficiency score is often shared by multiple DMUs. Many methods have been presented under the label of super-efficiency methods to rank and compare efficient units as in Noura et al. [18]. Wongchai et.al [19] explained that the basic idea of Super efficiency model is to compare the unit under evaluation with a linear combination of all other units in the sample where the DMU itself is excluded. Thus, an efficiency score that exceeds unity is obtained for the unit because the maximum proportional increase in inputs preserves efficiency, Sun and Lu [20]. According to Andersen and Petersen [21], the advantage of the SE-DEA model is that it permits us to rank efficient DMUs. where similar to CCR, it can provide a super-efficiency rating for efficient units. Meanwhile, the efficiency score of the inefficient DMUs remains consistent with CCR. The model of Super Efficiency DEA as in Pan et al. [22] where θ is a scalar that designates the share of the jth DMU's input vector, which is required in order to produce the *j*th DMU's output vector within the reference technology and describe as follows:

$$Min\ \theta$$

Subject to:

$$\sum_{\substack{k=1 \\ k \neq j}}^{n} v_k\ X_{k+s^-=\theta X_j}$$

$$\sum_{\substack{k=1 \\ k \neq j}}^{n} v_k\ Y_{k+s^-=Y_j}$$

$$v_k \geq 0,\ k = 1, 2, \ldots, n$$

$$s^- \geq 0, s^+ \geq 0,$$

where,
k = 1, 2, 3..., n are inputs
k = 1, 2, 3..., n are outputs
j = 1, 2, 3..., n are DMU's
v_k = intensity of the *k*th unit
X_j = *m*- dimensional input vector
Y_j = *s*- dimensional output vector

2.7 Validation of Model

Prior on choosing the best supplier, the correlation between the two methods will be computed as a validation process by using Spearman's Rank Correlation Coefficient (SRCC) which is also to observe the relationship of the two integration methods of AHP-DEA and EM-DEA in selecting the best supplier. The SRCC can be calculated as follows:

$$\text{SRCC} = 1 - \frac{6\sum di^2}{n\,(n^2-1)} \tag{12}$$

where
d_i= difference between rankings
n = sample size (supplier)

The SRCC value is in the range of -1 and 1 where the value that is near to -1 indicates negative correlation. On the other hand, if the SRCC value is near to 1, it indicates positive correlation. However, the data has no linear correlation if the SRCC value near to 0.

2.8 Rank of Supplier

The efficiency score obtained from the AHP-DEA and EM-DEA are used to determine the ranking of the supplier. The supplier with the highest efficiency score is ranked to select the best supplier.

3 Results and Discussions

This section discusses the findings of the integration methods of AHP-DEA and EM-DEA in the optimization of supplier selection problem.

3.1 Results of Weight of Criteria

Table 4 presents the weight of the five criteria that has been computed by using the approach of AHP and EM. The five criteria for the suppliers are Delivery (D), Capacity (Ca), Warranty (W), Cost (C), and Quality (Q). From the calculation using AHP, it shows that quality criteria has the highest value of weight which is 0.4872. By using EM, the cost has the highest value of weight with the value of 0.5397.

Table 4: Criteria's Weight for AHP and Entropy Measurement

Criteria	Criteria's Weight for AHP	Criteria's Weight for Entropy Measurement
Delivery (D)	0.0583	0.1678
Capacity (Ca)	0.0385	0.1715
Warranty (W)	0.2948	0.11
Cost (C)	0.1212	0.5397
Quality (Q)	0.4872	0.011

The different value of weights resulted from both methods can be observed in Table 4 as AHP is evaluated based on human judgment while the EM is calculated through data collection. The highest weight obtained means that the criteria is the most prioritize criteria perceived by the company.

3.2 Results of Efficiency Score of Data Envelopment Analysis (DEA)

The DEA CCR input oriented model integrated with AHP and EM is applied in the process to determine the efficiency score for each DMU. The result of the efficiency score is used to determine the rank for each supplier where the highest value will be at the first rank, while the lowest value of efficiency will be at the last rank. Then the rank of each supplier for both integration methods, AHP-DEA and EM-DEA are compared to see the pattern. Table 5 shows the comparison of efficiency score and rank of suppliers between integration methods of AHP-DEA and EM-DEA as well as single DEA CCR input oriented method.

It is shown that the AHP-DEA model has the highest efficiency score for each supplier as compared to the EM-DEA model. Supplier 3 is identified as the most efficient supplier with the highest score which is 1 for integration methods of AHP-DEA and EM-DEA as compared to the other suppliers. Supplier 5 is in the second rank from the result of the two methods with 0.8081833 and 0.7029792 scores respectively followed by Supplier 1 that is in the third rank with an efficiency score of 0.5762679 for the integration method of AHP-DEA and a score of 0.3103102 for integration method of EM-DEA. Next, the efficiency score for supplier 2 for the integration method of AHP-DEA is 0.5358688 while the efficiency score for integration method of EM-DEA is 0.1424218. Lastly, the efficiency score for supplier 4 for integration methods of AHP-DEA and EM-DEA are 0.5087053 and 0.1678731 respectively. However, supplier 2 and supplier 4 have distinct rankings for both integration methods due to different approach of weight calculation from AHP and EM. The efficiency result from single DEA CCR input oriented method by setting the weight on each supplier with the same value has resulted efficiency score of 1 for each supplier except for Supplier 2. Complete ranking among the efficient unit is not possible in standard DEA where this suggests that hybrid method of DEA and other methods such as AHP and EM are preferable since they can minimize the number of efficient units. It is also can be concluded that the weight of each criterion can slightly affect the efficiency of each supplier. Then, next analysis has been done through the result of ranking from efficiency score obtained from Super Efficiency DEA Method.

Table 5: Efficiency Score and Rank for AHP-DEA, Entropy Measurement-DEA and DEA

Supplier	Efficiency Score of AHP-DEA	Rank	Efficiency Score of EM-DEA	Rank	Efficiency Score of DEA	Ranking	Super Efficiency DEA Method	Rank
1	0.5762679	3	0.3103102	3	1.0000000	1	317.23%	2
2	0.5358688	4	0.1424218	5	0.7789603	2	77.90%	5
3	1.0000000	1	1.0000000	1	1.0000000	1	400.00%	1
4	0.5087053	5	0.1678731	4	1.0000000	1	166.48%	4
5	0.8081833	2	0.7029792	2	1.0000000	1	171.13%	3

3.3 Results of Validation of Model

The Spearman's Rank Correlation Coefficient (SRCC) method is used to compute the correlation between both integration methods. and identify a monotonic relationship between two variables. Since AHP is the method that is influenced by human judgment and EM is the method that rely on quantitative data, it is essential to justify the results on the two methods statistically. The interpretation values of the SRCC are stated in Table 6 while the SRCC values from the suppliers' ranking is presented in Table 7.

Table 6: SRCC Interpretation

SRCC Value	Interpretation
Closer to -1	Negative Correlation
Closer to 0	No Linear Correlation
Closer to 1	Positive Correlation

Table 7: Result of SRCC Value

Methods	SRCC Value	Interpretation
AHP-DEA and Entropy Measurement DEA	0.9	Positive Correlation
AHP-DEA and Super Efficiency Method	0.8	Positive Correlation
Entropy Measurement-DEA and Super Efficiency Method	0.9	Positive Correlation

Based on Table 7, the SRCC results show positive correlation between both integrated methods as well as positive correlation between both integrated method with Super Efficiency Method.

4 Conclusion

This study focuses on optimizing supplier selection for an apparel company situated in Kuala Lumpur, Malaysia using integration methods of AHP-DEA and AHP-EM model. There are five criteria of suppliers that have been considered, which are delivery, capacity, warranty, cost, and quality. The application of DEA method facilitates the decision-makers to select their suppliers according to the weight requirements of their respective criteria. This study has identified the values of each criteria's weight from AHP and EM methods, where AHP method is influenced by human judgement whereas EM is calculated from quantitative data. By integrating the weight obtained from AHP and EM, the DEA method is used to execute the efficiency of the suppliers. The efficacy of the proposed models is validated using SRCC method, which shows positive correlation between both integrated method as well as positive correlation between both integrated methods with another full ranking method of DEA which is Super Efficiency Method. The proposed method has made it possible for the supplier to be ranked according to their efficiency values, which make it easier for the organization and decision-makers to select their best supplier. Further study may be considered using more criteria such as service, management, reputation, risk, flexibility, and finance. Applying other mathematical method to be integrated with DEA methods can also be done for this type of optimization.

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