A Combined Approach for Sustainable Supplier Selection: A Case Study for a Manufacturing Firm

Gülçin Bektur

*Industrial Engineering, Iskenderun Technical University, 31200, Iskenderun, Hatay, Turkey

(gulcin.bektur@iste.edu.tr)

Tel: +90 326 613 5600

Received: 28.02.2018 Accepted: 17.02.2019

Abstract- Due to the increasing awareness of environmental and social issues, many researchers have paid much attention to the sustainable supplier selection. This paper addresses sustainable supplier selection problem. Although there are many studies on supplier selection, there is no study that takes into account the advantages of supplying two semi-parts from the same supplier. Supplying semi-parts from the same supplier which has similar production processes and which can transport simultaneously provides advantages to the firms in terms of price, transportation cost and resource consumption. In this study, suppliers were weighted by the AHP (Analytic Hierarchy Process) method. In addition, the contributions of supplying two semi-parts from the same supplier are determined by the AHP method. Mathematical model is used to determine the supplier for each semi-parts. The objective function of the mathematical model is maximizing total weights of the suppliers and contributions of the suppliying two semi- parts from the same supplier. The production capacities of suppliers were taken into account in the study. A case study is provided in a medical devices manufacturer to show the feasibility and effectiveness of the proposed methodology.

Keywords Sustainable supply chain management, Sustainable supplier selection, Mathematical model, AHP, Medical devices manufacturer, Contribution of supplying two semi- parts from the same supplier.

1. Introduction

Sustainable supply chain management (SSCM) has been considered as an integration and realization of economic, environmental and social objectives of a company in coordination of critical business processes to improve the company's long- term economic performance (Carter and Easton, 2011). Supplier is the one of the most critical factors for the success of Sustainable Supply Chains (SSC). Due to collaboration with economically, environmentally, and socially strong suppliers could improve the supply chain performance (Song et al., 2017). In the past, only economic criteria are used to evaluate suppliers. After SSCM's starting to attract increasing attention, researchers started to take into account social and environmental criteria while evaluating suppliers' performances. For sustainable supplier selection (SSS) researchers evaluate suppliers according to economic, social and environmental criteria.

A lot of study has been done for SSS problem. Bai and Sarkis (2010), proposed an approach that utilizes grey system and rough set theory. Lu et al. (2010), used fuzzy AHP for evaluating green suppliers' performances. Büyüközkan and Çifçi (2011), developed a novel approach based on fuzzy ANP within multi-person decision-making schema under incomplete preference relations. Amindoust et al. (2012), applied fuzzy logic and a new ranking method on the basis of fuzzy inference system for SSS problem. Govindan et al. (2013), used fuzzy set theory and fuzzy TOPSIS for SSS. Azadnia et al., (2014), proposed an integrated approach of rule-based weighted fuzzy method, fuzzy AHP and multi-objective mathematical model for SSS and order allocation. Jauhar and Pant (2017), proposed an efficient system for SSS by integrating together the traditional multi criteria performance evaluation tool DEA (Decision Envelopment Analysis) with DE (Diffirential Evaluation) algorithm and further with MODE (Multi-Objective Differential Evolution) to overcome the inherit drawbacks of DEA.

Luthra et al. (2017), proposed a framework to evaluate SSS by using an integrated AHP and VIKOR. Song et al. (2017), proposed a method integrates the merit of pairwise comparison method in determining relative importance, the strength of decision making trial and evaluation laboratory (DEMATEL). Lin et al. (2018), developed a decision model for decision- making in uncertain environments, one specifically tailored for managers in green supply chain management. Vahidi et al. (2018), suggested a hybrid SWOT - QFD (Quality Function Deployment) systematic framework for determining the sustainability criteria. Zhao and Guo (2014), proposed a hybrid fuzzy multi- attribute decision making approach (fuzzy entropy- TOTPSIS) for selecting the best green supplier. Jia et al. (2015), used TOPSIS for ranking potential suppliers among the pool of suppliers. Chung et al. (2016), proposed a green supplier selection and guidance mechanism by integrating the features of ANP and an IPA (importance performance analysis) to achieve sustainable management for green supply chains.

In this study, SSS problem is tackled by an integrated approach. First of all, suppliers are weighted by AHP. If two products are supplied from the same supplier, suppliers can provide cost reduction. Also, if the products are transported simultaneously, supplying semi- parts from the same supplier can also reduce the transportation cost. Taking the scale economy into consideration, supplying two semi- parts from the same supplier can lead to a decrease in resource consumption compared to the situation of supplying from different suppliers. As a result, if two products are supplied from the same supplier, there is a contribution. This contribution was also determined by AHP. Finally, supplier for each products is determined using mathematical model. The objective function of the mathematical model is maximizing the total contribution of supplying two semi- parts from same supplier and total weights of the suppliers. Although there are many studies in the literature about supplier selection, there is no study that takes into consideration the contribution of supplying two semi- parts from the same supplier.

The paper is organized as follows: In Section 2, methodology is presented. In section 3 a case study for a medical devices manufacturer firm is presented. Finally, conclusions are given in Section 4.

2. Methodology

2.1. AHP

AHP is a popular method for tackling multicriteria analysis problems involving qualitative data and has been applied successfully to many actual decision situations (Ayağ, 2007).

The steps of the AHP method are as follows (Saaty, 1981):

Step 1: Define the problem and determine its goal.

Step 2: Structure the hierarchy from the top (the objectives from a decision-maker's viewpoint) through the intermediate levels (criteria on which subdequent levels depend) to the lowest level which usually contains the list of alternatives.

Step 3: Construct a set of pairwise comparison matrices (size n×n) for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale measurement. The pairwise comparisons are done in terms of which element dominates the other.

Step 4: There are n(n-1) judgements required to develop the set of matrices in Step 3. Reciprocals are automatically assigned in each pairwise comparison.

Step 5: Hierarchical synthesis is now used to weight the eigenvectors by the weights of the criteria, and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.

Step 6: Having made all pairwise comparisons, the consistency is determined by using the eigenvalue λ_{max}, to calculate the consistency index, CI, as follows Eq. (1) (Dağdeviren, 2008):

$$CI=\frac{(\lambda_{max}-n)}{n-1} \quad (1)$$

where n is the matrix size. Judgement consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value, as follows Eq. (2) [5].

$$CR=\frac{CI}{RI} \quad (2)$$

The CR is acceptable, if it does not exceed 10%. RI is the average index for randomly generated weights (Saaty, 1989).

2.1.1. Criteria of AHP for calculating weights of the suppliers

For determining the criteria, a decision group is formed that consists of six experts (two academicians and four senior level managers from the case company). The inputs of the decision group and a literature analysis are used to select the criteria of SSS for sustainability in supply chain. AHP is used for determining the weights of suppliers. Table 1 summarizes the sustainable supplier selection criteria used by AHP. Price, quality and transportation cost are economical, resource consumption and environmental management system are environmental criteria and occupational health and safety system and information disclosure are social criteria. Implementation of AHP is given on Section 3.

Table 1. Sustainable supplier selection criteria

No	Criteria	Description
1	Price (P)	Capability of supplying the products at reasonable price
2	Quality (Q)	Providing a significant quality level

3	Transportation cost (TC)	The tendency of shipping products at minimum transportation cost
4	Resource consumption (RC)	The use of resources, including energy, power and water, are to be reduces by the practices such as modifying production maintanence and process, conservation, recycling and reusing materials
5	Environmental Mang. System (EMS)	A set of systematic processes and practices that enable a supplier to reduce its environmental impacts, with includes the organizational structure, planning and implementing policy (e.g., ISO 14001 and TQEM) for environmental protection
6	Occup. Health Safety Sys. (OHSS)	It is concerned with the safety, health and welfare of the people engaged at supplier's workplace
7	Inf. Disclosure (ID)	Providing inf. to their customers and stakeholders regarding material used, carbon emissions and toxins released during production etc.

2.1.2. Criteria of AHP for calculating contribution of supplying two semi- parts from the same supplier

If semi-parts are purchased from the same supplier, suppliers can provide price reductions. For this reason, price is a criterion for calculating the contribution of supplying two semi-parts from the same supplier. In particular, the production of semi -parts with similar production processes by the same supplier may result in a reduction in the amount of raw materials and energy used. As a results semi –parts that uses the same machines affect resource consumption criteria positevely. In many firms, machines that are used for production is prepared before the production. This set up time is decreased, if similar products are produced successively. This situation effects the resource consumption positively. As a result, due to the economics of the scale, fixed costs for production of the same or similar types of products in the same supplier are decreasing. If semi-parts supplied from the same suppliers able to transport together can make advantages in terms of transportation cost.

In this study, semi-parts are classified according to their types. Alternatives are the dual combination of product types. The number of alternatives is equal to h(h+1)/2 (h: number of semi–parts types). Supplying the same types of semi- parts from the same supplier does not always provide higher contribution than the different types of semi-parts. For example, considering transportation cost, small semi-parts that can be transported together with large semi-parts can contribute more than the supplying same types of semi-parts from the same supplier. As a result, the contribution of supplying two semi–parts from the same supplier is calculted by AHP. Implementation of AHP is given on Section 3.

2.2 Mathematical Model

The mathematical model used to identify the appropriate supplier for each semi- parts is given below.

Sets:

J= Set of all parts{1,…,n}

K= Set of all suppliers {1,…,m}

R= Set of part types {1,…,h}

B_r= Set of parts for which the type of the parts are r ∈ R

Parameters:

p_k: weight of supplier k

q_{ij}: contribution obtained if parts i and j are supplied from the same supplier

c_{kr}: capacity of supplier k for the type r

Decision Variable

$$x_{jk}: \begin{cases} 1; & \text{If item } j \text{ is supplied by the supplier } k \\ 0; & \text{otherwise} \end{cases}$$

Model:

$$Max\ Z = \sum_j \sum_k p_k\, x_{jk} + \sum_k \sum_{i<n} \sum_{j>i} q_{ij}\, x_{ik} x_{jk} \quad (1)$$

subject to

$$\sum_{j \in J_r} x_{jk} \le c_{kr} \quad \forall\, k,r \quad (2)$$

$$\sum_k x_{jk} \le 1 \quad \forall\, j \quad (3)$$

$$x_{jk} \in \{0,1\} \quad (4)$$

The objective function of the model is given in (1) which maximizes total suppliers' weights and contributions of the parts that is supplied from the same supplier. The capacity constraints of suppliers are imposed in (2). Constraint (3) guarantees that each item can be selected for only one supplier. (4) is sign constraint.

3. A Case Study for a Medical Devices Manufacturer Firm

The application was made in a company that manufactures medical devices. The company is experiencing various problems in its procurement process. It decided to work with sustainable suppliers. There have been 3 types of semi-parts that the suppliers must be determined. 5 alternative suppliers are available. The number of each types of semi-parts and capacity of the suppliers are given in Table 2 and Table 3.

Table 2. Number of semi- parts according to semi- part type

Semi- part type	Number of semi- parts
1	22
2	62
3	85

Table 3. Capacity of the suppliers according to semi-part type

Supplier	Capacity		
	Semi- part type 1	Semi- part type 2	Semi- part type 3
1	5	-	50
2	-	40	10
3	5	45	-
4	12	20	30
5	12	10	5

Phase I: Compute weights of the alternative suppliers using AHP

Structural hierarchy of AHP is given in Figure 1.

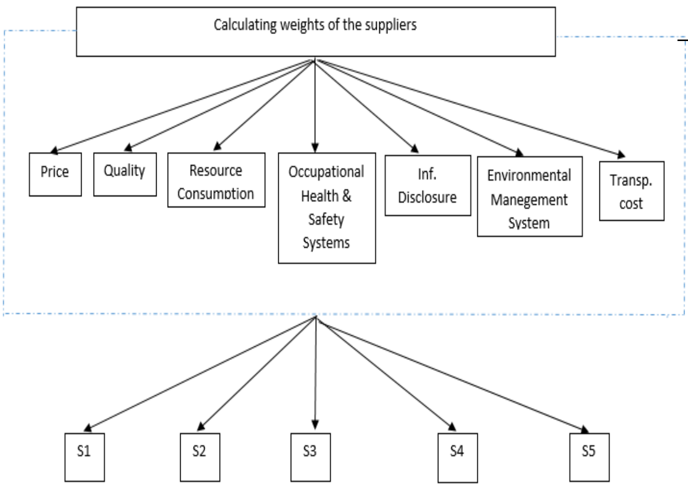

Figure 1. Hierarchy of AHP

Pairwise comparisons of criteria and importance weights of the criteria are given on Table 4. The critical ratio (CR) value is 0.08159.

Table 4: Pairwise comparisons of criteria and importance weights of the criteria

Criteria	Pairwise Comparisons							Importance weights
	P	Q	TC	RC	EMS	OHSS	ID	
P	1	1/2	1	2	3	2	3	0.2027
Q	2	1	1	2	2	2	2	0.2140
TC	1	1	1	1	1	2	1/3	0.1308
RC	1/2	1/2	1	1	2	1	1	0.1154
EMS	1/3	1/2	1	1/2	1	3	1/2	0.1037
OHSS	1/2	1/2	1/2	1	1/3	1	1/2	0.0775
ID	1/3	1/2	3	1	2	2	1	0.1559

The results of comparison of the suppliers according to criteria are given on Table 5. The CR values are smaller than 0.1 for all criteria. The final result of AHP is given on Table 6. By using AHP suppliers are weighted and these weights are used as parameters of the mathemetical model.

Table 5. The results of comparison of the suppliers according to criteria

Criteria	Supplier-1	Supplier-2	Supplier-3	Supplier-4	Supplier-5	CR Value
P	0.2523	0.1062	0.0994	0.2897	0.2524	0.03647
Q	0.2915	0.1052	0.0756	0.1705	0.3572	0.02500
TC	0.1706	0.3578	0.2845	0.1003	0.0868	0.01416
RC	0.0881	0.1854	0.1167	0.2323	0.3775	0.03564
EMS	0.0902	0.3559	0.2709	0.1872	0.0958	0.02141
OHSS	0.0804	0.2853	0.3553	0.1395	0.1395	0.00811
ID	0.2467	0.2688	0.1146	0.1233	0.2466	0.00443

Table 6. Result of AHP

Supplier	Weight
1	0.2000
2	0.2132
3	0.1606
4	0.1845
5	0.2417

As a conclusion, according to the result of AHP the best supplier is 5 with the weight of 0.2417. These weights are used as a parameter fort he mathematical model. By using mathematical model, the semi-parts are supplied from the supplier with the highest weight as much as possible.

Phase II: Compute the contribution of the products that is supplied from the same supplier

Criteria are price, resource consumption and transportation cost. Structural hierarchy of AHP is given in Figure 2. According to Fig 2, 1-1 shows the two semi- parts that the part type is 1. And also, 1-2 shows two semi- parts that the type of one is 1 and another is 2. Other alternatives can be considered in a similar way. Pairwise comparisons of criteria and importance weights of the criteria are given on Table 7. The critical ratio (CR) value is 0.04625.

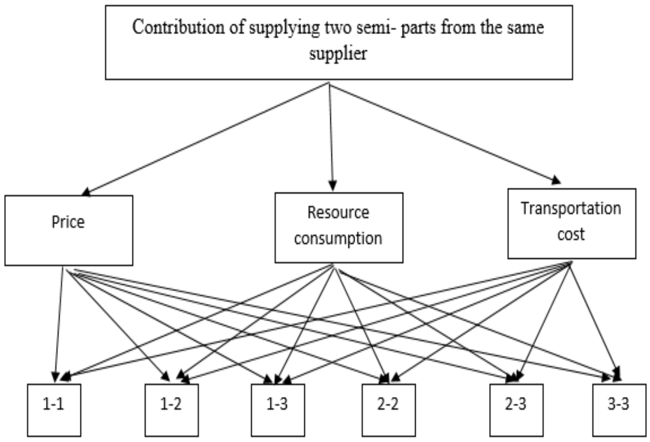

Figure 2. Hierarchy of AHP

Table 7. Pairwise comparisons of criteria and importance weights of the criteria

Criteria	Pairwise Comparisons P	TC	RC	Importance weights
P	1	1	2	0.4111
TC	1	1	1	0.3277
RC	1/2	1	1	0.2612

In terms of price criterion, the alternatives are compared and the following Table 8 is obtained. CR value of comparison of alternatives according to price criterion is 0.03806.

The results of comparison of the suppliers according to criteria are given on Table 9. The CR values are smaller than 0.1 for all criteria. By using AHP contribution of supplying two semi- parts from the same supplier is determined and these contributions are used as parameters of the objective function of the mathematical model. Mathematical model is used for determining the supplier for each semi –parts. Parameters of the mathematical model are capacities of the suppliers according to product types, weights of the suppliers and contribution of supplying two semi-parts from the same supplier (q_{ij}). q_{ij} values were calculated by AHP.

Table 8. The results of comparison of the suppliers according to criteria

Criteria	1-1	1-2	1-3	2-2	2-3	3-3	CR Value
P	0.2552	0.1162	0.0797	0.2526	0.1236	0.1727	0.03806
RC	0.2675	0.1449	0.0954	0.1914	0.0942	0.2066	0.04017
TC	0.0785	0.1906	0.1719	0.2059	0.1374	0.2157	0.08990

Table 9. Result of AHP

Alternatives	Weights
1-1	0.1992
1-2	0.1481
1-3	0.1141
2-2	0.2214
2-3	0.1205
3-3	0.1957

As a conclusion, according to the AHP results, the highest contribution is satisfied by supplying type 2 semi-parts from the same supplier.

Phase III: Determining the suppliers using mathematical model

The first 22 semi- parts are in type1, semi parts numbered between 23 and 84 are in type 2, semi parts numbered between 85 and 169 are in type 3. q_{ij} values of the semi- parts are given on Figure 3. The values of Figure 3 are obtained by AHP.

Capacities of the suppliers and weights of the suppliers are given on Table 3 and Table 6 respectively.

The model is solved with GAMS/ DICOPT solver. The result of the problem is given on Figure 4.

		Type 1				Type 2				Type 3			
		1	2	...	22	23	24	...	84	85	86	...	169
Type 1	1	-	0.2552	...	0.2552	0.1162	0.1162	...	0.1162	0.0797	0.0797	...	0.0797
	2	0.2552	-	...	0.2552	0.1162	0.1162	...	0.1162	0.0797	0.0797	...	0.0797
	.	.	.		.	.	.		.	.	.		.
	.	.	.	...	.	.	.	...	.	.	.	...	.
	.	.	.		.	.	.		.	.	.		.
	22	0.2552	0.2552	...	-	0.1162	0.1162	...	0.1162	0.0797	0.0797	...	0.0797
Type 2	23	0.1162	0.1162	...	0.1162	-	0.2526	...	0.2526	0.1205	0.1205	...	0.1205
	24	0.1162	0.1162	...	0.1162	0.2526	-	...	0.2526	0.1205	0.1205	...	0.1205
	.	.	.		.	.	.		.	.	.		.
	.	.	.	...	.	.	.	...	.	.	.	...	.
	.	.	.		.	.	.		.	.	.		.
	84	0.1162	0.1162	...	0.1162	0.2526	0.2526	...	-	0.1205	0.1205	...	0.1205
Type 3	85	0.1141	0.1141	...	0.1141	0.1205	0.1205	...	0.1205	-	0.1957	...	0.1957
	86	0.1141	0.1141	...	0.1141	0.1205	0.1205	...	0.1205	0.1957	-	...	0.1957
	.	.	.		.	.	.		.	.	.		.
	.	.	.	...	.	.	.	...	.	.	.	...	.
	.	.	.		.	.	.		.	.	.		.
	169	0.1141	0.1141	...	0.1141	0.1205	0.1205	...	0.1205	0.1957	0.1957	...	-

Figure 3. The parameter of q_{ij}

According to the result, the capacities of suppliers are not exceeded. Each product is supplied from a supplier. And as possible as, semi- parts are supplied from the suppliers that has high values of weights and the semi parts that are provided high value of contribution in case of supplying from the same suppliers are supplied as possible as from the same supplier.

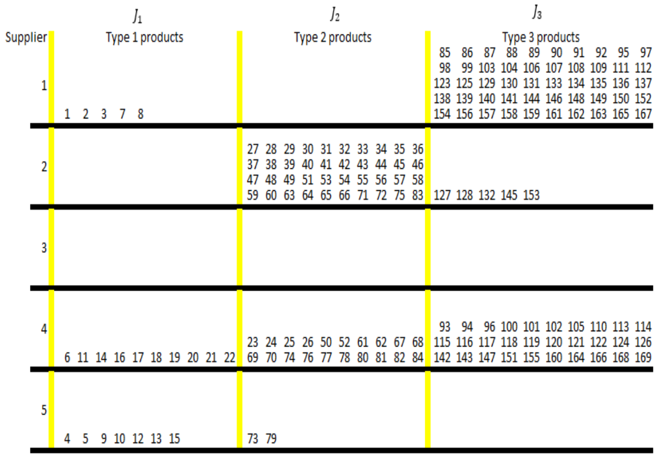

Figure 4. Result of the mathematical model

As a conclusion, according to the Figure 4, semi- parts 1, 2, 3, 7 and 8 are supplied from supplier 1. And the suppliers of the other semi- parts are given on Figure 4.

4. Conclusions

In this study, the problem of sustainable supplier selection has been examined. A combined approach is proposed for the problem. Alternative sustainable suppliers are weighted by AHP. Contribution of supplying two semi–parts from the same supplier is calculated also AHP. Mathematical model is used for determining the supplier for each semi –parts. The results of AHP are used as parameters of the objective function of the mathematical model. The objective function of the mathematical model is maximizing total weights of the suppliers and contribution of supplying two semi parts from the same supplier. The proposed approach is applied for manufacturer firm. As a result, optimal supplier is dertemined for each semi parts. The proposed approach might be also applied using fuzzy set theory in future research.

References

[1] C. R. Carter, and P. L. Easton, “Sustainable supply chain management: evolution and future directions”, International journal of physical distribution and logistic management, vol. 1, pp. 46-62, 2011.

[2] W. Song, Z. Xu, and H. C. Liu, “Developing sustainable supplier selection criteria for solar- air conditioner manufacturer: An integrated approach”, Renewable and sustainable energy reviews, pp. 1461-1471, 2017.

[3] C. Bai, and J. Sarkis,” Integrating sustainability into supplier selection with grey system and rough set methodologies”, International journal of Production Economics, pp. 252-264, 2010.

[4] Y. Lu, H. Wu, and C. Kuo, “Environmental principles applicable to green supplier evaluation by using multi objective decision analysis”, International journal of production research, vol 18, pp. 4317- 4331, 2010.

[5] G. Büyüközkan, and G. Çifçi, “A novel fuzzy multi-criteria decision framework for sustainable supplier selection with incomplete information”, Computers in Industry, pp. 164-174, 2011.

[6] A. Amindoust, S. Ahmed, A. Saghafinia, and A. Bahreininejad, “Sustainable supplier selection: A ranking model based on fuzzy inference system”, Applied soft computing, pp. 1668- 1677, 2012.

[7] K. Govindan, R. Khodaverdi, and A. Jafarian, “A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach”, Journal of Cleaner Production, pp. 345-354, 2013.

[8] H. Azadnia, M. Saman, and Y. Wong, “Sustainable supplier selection and order lot- sizing: an integrated multi- objective decision- making process”, International journal of production research, vol. 2, pp. 383-408, 2014.

[9] K. Jauhar, and M. Pant, “Integrated DEA with DE and MODE for sustainable supplier selection”, Journal of Computational Science, pp. 299- 306, 2017.

[10] S. Luthra, K. Govindan, D. Kannan, K. Mangla, and P. Garg, “An integrated framework for sustainable supplier selection and evaluation in supply chains”, Journal of Cleaner Production, vol. 3, pp. 1686- 1698, 2017.

[11] P. Lin, C. Hung, T. Lin, and H. Hsieh, “Green suppliers performance evaluation in Belt and Road using fuzzy weighted average with social media information”, Sustainability, vol. 1, 2018.

[12] F. Vahidi, A. Torabi, and J. Ramezankhani, “ Sustainable supplier selection and order allocation under operational and disruption risks”, Journal of Cleaner Production, pp. 1351-1365, 2018.

[13] H. Zhao, and S. Guo, “Selecting green supplier of thermal power equipment by using a hybrid MCDM method for sustainability”, Sustainability, vol. 1, pp. 217-235, 2014.

[14] P. Jia, K. Govindan, M. Choi, and S. Ragendran, “Supplier selection problems in fashion business operations with sustainability considerations”, Sustainability, vol. 2, pp. 1603-1619, 2015.

[15] C. Chung, C. Chao, and J. Lou, “The establishment of a green supplier selection and guidance mechanism with the ANP and IPA”, Sustainability, vol. 3, pp. 259-283, 2016.

[16] Z. Ayağ, "A hybrid approach to machine- tool selection through AHP and simulation", International journal of production research, vol. 9, pp. 2029-2050, 2007.

[17] T. L. Saaty, "The Analytical Hierarchical Process", 1981, McGraw Hill, New York.

[18] M. Dağdeviren, "Decision making in equipment selection: an integrated approach with AHP and Promethee". J. Intell. Manuf., pp. 397-406, 2008.

[19] Saaty, T. L., "Decision making, scaling, and number crunching", Decision Science, pp. 404-409, 1989.