Journal of Optimization in Industrial Engineering 21 (2017) 19-28

Agile Supplier Selection in Sanitation Supply Chain Using Fuzzy VIKOR Method

Mohammadreza Shahriari[a,*], Nazanin Pilevari[b]

[a] *Associate Professor, Faculty of Management, South Tehran Branch, Islamic Azad University, Tehran, Iran*
[b] *Assistant Professor, Department of Industrial Management, College of Management and Accounting, Yadegar-e-Imam Khomeini (RAH) Branch, Islamic Azad University, Tehran, Iran.*

Received 12 November 2015; Revised 09 February 2016; Accepted 18 February 2016

Abstract

Regarding the diversified needs of the customers and various products of competitors, the importance of agility in supply chain management becomes more significant. Suppliers should provide materials and essential resources of manufacturers without any lead time. In this research, we used a two-stage method for supplier selection. In the first stage, we used a new Data Envelopment Analysis (DEA) method based on network framework to determine the efficiency of the suppliers. This model considered 4 layers for supply chain of each supplier. At the end of this stage, the better suppliers have been selected for the second stage. In the second stage, after determining the efficient suppliers, we identified several criteria for agility in sanitation supply chain. Due to the uncertainty on the supplier's data, we used a fuzzy Delphi method and ideas of experts about those criteria have been finalized in 8 criteria. Next step was devoted to prioritization of 5 selected suppliers in sanitation industry based on the final criteria with fuzzy VIKOR.
Keywords: Network DEA, Two-stage method, Sanitation supply chain, Agile supply chain, Fuzzy VIKOR.

1. Introduction

Today, many companies are facing with an increasingly competitive situation resulting from changes in customer demands, as well as market and technological innovations. The surrounding environment of organizations is rapidly changing. Agile organizations and individuals adapt themselves to advanced technology to meet the customers' needs in a relatively short time. Organizations should find more efficient suppliers to increase the competitiveness of their supply chain. Among different available suppliers, choosing suppliers who can build a long-term relationship and having cooperation with each other is a key issue in increasing its efficiency. To provide the necessary materials for organizations' output, vendor selection and evaluation is a general problem. Evaluating the best or more suitable supplier based on its abilities is different from one to another, especially when shopping is complex and the value is high. This work requires a formal process of evaluating and grading the suppliers. Supplier selection process is in fact a problem-solving process, which includes problem definition, formulation of characteristics, determining eligibility, and selection. In 1960, when Dixon proposed 23 different selection Criteria, many articles were published about the analysis of supplier selection criteria.

* Corresponding author Email address: shahriari.mr@gmail.com

Given the importance of the agility and criteria, 2 questions will arise:

- What are the criteria and indicators for evaluating the suppliers of cosmetic products?
- How much are the weight and final rank of each supplier based on the agile supply chain?

In this paper, we used a new 2-stage supplier selection method. In the first stage, we consider that each supplier has a 4-layer supply chain. We used a network DEA for connecting the inputs and outputs of the suppliers supply chain with their middle layers. In this stage, the efficient suppliers have been selected. In the second stage, we consider 9 criteria for each supplier and based on them, we used a fuzzy VIKOR model to rank these selected suppliers.
This paper is divided into 7 parts. The second part is the literature review. In parts 3 and 4, we present DEA concepts and mathematical model of the first stage. Part 5 is a fuzzy VIKOR model, and part 6 deals with agile sanitation and cosmetics supply chain. The selected suppliers were ranked in these 2 parts and the final part will discuss conclusion and further studies.

3. Network Data Envelopment Analysis

3.1. Nomenclature

m_k	Number of inputs in k^st section
i	Section input index
r_k	Section output index
K	Number of sections
k	Section index
n	Number of DMU's
j	DMU index
x_{ij}^{k}	Input of k^st section for j^st DMU
$y_{r_k j}^{k}$	r_k^st output in section k for j^st DMU
$y_{r_k o}^{k}$	r_k^st output in section k for j^st under evaluation DMU
$z_{S(k,h)j}^{(k,h)}$	The value of the middle section from section k to section h for jst DMU
$S_{(k,h)}$	Number of the middle section from section k to section h for jst DMU
S_r^k	Output deficiency of k^st section
λ_j^k	Intensity vector of section k for j^st DMU
τ_o^*	Total efficiency of DMU
w^k	The weight of k^st section

3.2. Mathematical Model

The presented model based on the network framework of system is as Eq. (1)-(4).

$$\max \frac{1}{\tau_{\text{O}}^{*}} = \sum_{n=1}^{k} w^k \left(1 + \frac{1}{r_k} \sum_{r=1}^{r_k} \frac{s_r^{k+}}{y_{ro}^{k}}\right) \tag{1}$$

$$\sum_{j=1}^{n} x_{ij}^{k}.\lambda_j^k \le x_{ro}^{k} \quad ; \quad i = 1,2,\dots,m_k \quad ; \quad k = 1,2,\dots,k \tag{2}$$

$$\sum_{j=1}^{n} y_{rj}^{k}.\lambda_j^k + S_r k = y_{ro}^{k} \quad ; \quad i = 1,2,\dots,m_k \,; k = 1 \tag{3}$$

$$\sum_{j=1}^{n} \sum_{S(k,h)=1}^{S(k,h)} Z_{S(k,h)j}^{(k,h)} \lambda_j^k = \sum_{j=1}^{n} \sum_{S(k,h)=1}^{S(k,h)} Z_{S(k,h)j}^{(k,h)} \lambda_j^h \tag{4}$$

$$\lambda_j^h, S_r^{k+} \ge 0$$

3.3. The Numerical Example 1

In the first stage, we have 10 suppliers and each supplier has 4 supply chain layers. The important weights of the layers are 0.2, 0.3, 0.1, and 0.4. The input values of the DMUs, layers values, and the output values of DMUs are presented in Tables 2, 3, and 4.

We solved the presented model with Lingo, and the results are presented in Figure 1 and Table 5. Based on this model, the efficient suppliers are number 1, 2, 4, 8, and 10.

Table 1
Extracted parameters for supplier selection in agile supply chain

Index	Author(s)	Year	Index	Author(s)	Year
Cost and price	Agarwal et al., Alimardani et al.	2006 2013	Reputation and experience and past performance	De Boer et al., Rahiminezhad et al.	2001 2013
Quality	Gunasekaran, Wu & Barnes, Rahiminezhad et al.	2008 2008 2013	Flexibility	Alimardani et al.	2013
Delivery speed and time delay reduction	Agarwal et al., Wu & Barnes, Alimardani et al.	2006 2008 2013	Commitment	Wu & Barnes, Rahiminezhad et al.	2008 2013
Customer satisfaction	Gunasekaran, Luo et al., Alimardani et al.	2008 2009 2013	International relations	Asif Hasan et al., Rahiminezhad et al.	2008 2013
Proximity	Asif Hasan et al., Rahiminezhad et al.	2008 2013	After-sales service	Luo et al., Alimardani et al.	2009 2013
Production capacity	Vinodh et al.	2011			

Table 5
The efficiency of each DMU

10	9	8	7	6	5	4	3	2	1	DMU
1	1.5206	1	1.4915	1.4181	2.4314	1	3.7424	1	1	τ
1	0.6576	1	0.6704	0.7051	0.4112	1	0.2672	1	1	Efficiency

The values presented in table 5 showed that suppliers number 1, 2, 4, 8, and 10 are efficient and other suppliers have no efficiency. So, the efficient suppliers have been selected for ranking in the second stage.

4. Fuzzy VIKOR Method

4.1 Formation of Decision Matrix

According to the number of criteria, number of options, and evaluation of all options for different criteria, decision matrix is formed as follows:

$$D = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{nm} \end{bmatrix}$$

where X_{ij} is the performance of j^{th} option (j=1, 2 … n) in relation to the criteria of the i (i = 1, 2 ... m).

Determining the criteria weight matrix:

In this stage, given the importance of the different criteria in deciding factor, the matrix is defined as follows:

$W = [w_1, w_2 \cdots w_n]$

It determines the best and worst values from the available values of each criterion in the decision matrix.

The best and worst values for positive and negative criteria are listed in Table 6 as follows:

Table 6
The best and worst values for positive and negative criteria

Type of criteria	Best	Worst
Positive criteria	$f_i^* = maxf_{ij}$	$f_i^- = minf_{ij}$
Negative criteria	$f_i^* = minf_{ij}$	$f_i^- = maxf_{ij}$

Where f_i^* is the best value of i^{th} criteria among all options and f_i^- is the worst value of i^{th} criterion among all options.

Calculation of S and R values:

S and R values are calculated according to Eqs. (5) and (6). W_i is the desired weight for the i^{th} criterion.

$$\tilde{S}_i = \sum_{i=1}^{k} \frac{\tilde{w}_j (\tilde{f}_j^* - \tilde{x}_{ij})}{(\tilde{f}_j^* - \tilde{f}_j^-)} \tag{5}$$

$$\tilde{R}_i = \max_j \left[\frac{\tilde{w}_j (\tilde{f}_j^* - \tilde{x}_{ij})}{(\tilde{f}_j^* - \tilde{f}_j^-)} \right] \tag{6}$$

Calculation of Q:

Q is calculated according to Eq. (7):

$$Q_j = v \frac{(S_j - S^*)}{(S^- - S^*)} + (1-v) \frac{(R_j - R^*)}{(R^- - R^*)} \tag{7}$$

$$\tilde{S}^* = \min_i \tilde{S}_i , \tilde{S}^- = \max_i \tilde{S}_i \tag{8}$$

$$\tilde{R}^* = \min_i \tilde{R}_i , \tilde{R}^- = \max_i \tilde{R}_i \tag{9}$$

V parameter is chosen according to the group consensus decision, so that in the case of unanimous vote, it is higher than 0.5; in the case of agreement with the majority vote, it is equal to 0.5; in the case of low agreement, it is lower than 0.5.

Sorting options is based on the reduction of S, R, and Q values.

In this stage, options are sorted given the values of S, R, and Q. Finally, an option will be selected as the best option when it is known as the best option among all 3 groups. The placement options are according to the reduction of R, S, and Q. It should be noted that in Q group, the best option should satisfy the following 2 conditions.

Condition 1: If $A^{(1)}$ and $A^{(2)}$ are the first and second best options in group Q, respectively, and n is the number of options, the Eq. (10) will be satisfied:

$$Q(A^{(2)}) - Q(A^{(1)}) \geq \frac{1}{n-1} \tag{10}$$

Condition 2: Option $A^{(1)}$ must be recognized as the best option at least in either of R or S groups.

When the first condition is not established, a set of options to choose the best option are presented as Eq. (11):

$$Best\ Options = A^{(1)}, A^{(2)} \cdots A^{(M)} \tag{11}$$

The highest value of M is calculated as Eq. (12):

$$Q(A^{(M)}) - Q(A^{(1)}) \geq \frac{1}{n-1} \tag{12}$$

When the second condition is not established, the two options, $A^{(1)}$ and $A^{(2)}$, are chosen as the top choices.

5. Agile Sanitation and Cosmetics Supply Chain

Cosmetics and sanitation is a global industry. It is remarkable that the system puts all these functions together and any number of snags and meltdowns can occur as packages moving from warehouse to warehouse across the globe. Ensuring that finished products are available for sale at a retail cosmetic counter is dependent

Table 12
Unscaled fuzzy decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9
Weights	(0.5,0.5,0.62,0.83)	(0.6,0.8,,1,1)	(0.6,0.8,1,1)	(0.55,0.73,0.93,0.95)	(0.55,0.73,0.86,0.94)	(0.6,0.8,1,1)	(0.6,0.8,1,1)	(0.57,0.74,0.95,0.98)	(0.55,0.73,0.93,0.95)
A1	(0.62,0.71,0.83,1)	(0.5,0.7,0.8,1)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)
A2	(0.55,0.62,0.62,0.71)	(0.8,0.9,1,1)	(0.8,0.9,1,1)	(0.7,0.867,0.933,1)	(0.8,0.9,1,1)	(0.7,0.867,0.933,1)	(0.7,0.867,0.933,1)	(0.8,0.9,1,1)	(0.7,0.867,0.933,1)
A3	(0.5,0.53,0.57,0.71)	(0.7,0.833,0.867,1)	(0.7,0.867,0.933,1)	(0.8,0.9,1,1)	(0.7,0.833,0.867,1)	(0.7,0.867,0.933,1)	(0.8,0.9,1,1)	(0.7,0.833,0.867,1)	(0.7,0.867,0.933,1)
A4	(0.55,0.62,0.62,0.71)	(0.5,0.733,0.767,0.9)	(0.5,0.667,0.733,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.833,0.867,1)	(0.7,0.8,0.8,0.9)	(0.7,0.8,0.8,0.9)	(0.7,0.833,0.867,1)	(0.7,0.8,0.8,0.9)
A5	(0.62,0.71,0.83,1)	(0.5,0.733,0.767,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.667,0.733,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.667,0.733,0.9)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)

Then, the calculated weights for each criterion were entered in the unscaled matrix, and the weighted matrix was computed in Table 13.

5.2. Determining the Best and the Worst Values for Each Criterion

After determining the unscaled matrix, the best and the worst values were determined. Then, these values were specified in Table 14.

As described in the previous section, ranking of the suppliers is done by fuzzy VIKOR. Since the final data were fuzzy, they must have been converted to definitive data in order to rank them, and then based on the minimum value of Q, alternatives (suppliers) could be ranked. Conversion of fuzzy data to definitive data is done by the following formula:

$$Q_i = (q_1, q_2, q_3, q_4) = \frac{a + 2(b + c) + d}{6}$$

Table 15 shows the values of S, R, and Q:

Ranking of suppliers by VIKOR method

Suppliers	$\tilde{S}$	$\tilde{R}$	$\tilde{Q}$	Q	Final Rank
A_1	(0.42,0.78,2.23,4.08)	(0.0012, 0.0172, 0.1972, 0.3998)	(0.214,0.302,0.641,0.821)	0.51	2
A_2	(0.38,0.61,1.19,3.19)	(0.0160, 0.0807, 0.3470, 0.5626)	(0.065,0.165,0.472,0.604)	0.38	1
A_3	(0.45,0.89,1.16,2.94)	(0.019, 0.084, 0.145, 0.267)	(0.301,0.522,0.789,0.952)	0.61	3
A_4	(0.32,0.82,1.21,3.17)	(0.012,0.123,0.23,0.38)	(0.503,0.752,0.893,0.995)	0.79	5
A_5	(0.31,0.92,2.1,3.82)	(0.0126, 0.0505, 0.1212, 0.3009)	(0.45,0.651,0.808,0.894)	0.68	4

In the above Table, all stages of Fuzzy VIKOR method are presented and the results show that the supplier number 2 is the best option to choose in the agile supply chain. Also, suppliers number 1 and 5 are in the next lines, and suppliers 3 and 4 are in the fourth and fifth positions.

6. Conclusion and Further Studies

According to the results of research, the following practical suggestions are offered:

- **Establishing long-term relationships with suppliers**

The importance of agility in the production on one hand and long-term relationship with suppliers on the other were mentioned here. So, managers and experts can select suppliers with the highest rank based on this model. Decision-making in the supply chain is done for the long-term relationship; if the agility criteria have direct intervention in decisions, managers can ensure the agility of their supply.

Based on the results, supplier number 2 has the top place. Thus, it is recommended for the managers to have relations with supplier number 2. Also, if a company wants to have relations with other suppliers, suppliers 1 and 5 are the best options.

- **Preferring an appropriate model of assessment and decision-making on the current method**

Supplier is one of the critical elements of the supply chain, and its selection requires careful and comprehensive evaluation. The current method in selecting suppliers is not accurate and documented. Sometimes, it involves personal opinions in the selection of suppliers and causes disruptions in the supply chain objectives. Thus, evaluation and selection of suppliers in a company needs a system, which has predetermined criteria and follows certain choices and determines principles. In the proposed method, we tried to apply both criteria and managers' opinion, so that a strong and reliable model for supplier selection can be created.

- **Importance of considering the criteria of agility in choosing a supplier**

Change and turmoil in many markets have become an integral part of the business. Thus, supply chain managers must accept uncertainty and meanwhile, organize and develop an appropriate strategy with an acceptable cost to coordinate the supply and demand. This ability is called supply chain agility. Given the importance of supply chain agility competition in domestic and foreign products, agility criteria in the supply chain should be considered in selecting a supplier. Therefore, the selection of a supplier that has the characteristics of agile supply can be guaranteed.

- **Considering the relationship between evaluation and selection criteria for selecting appropriate supplier**

The results of this study indicate that the relationship between the evaluation and selection criteria is effective on the weight of criteria and suppliers' ranking. Thus, using the methods which involve these relationships is effective in creating more real results.

- **Using ordering models based on reality**

Most organizations and scientific studies have not included the opportunity costs such as inventory costs or shipping costs in these models. Also, they considered price inflation as a subjective measure of the model that is in fact an objective one.

References

Agarwal, A., Shankar, R. & Tiwari, M. (2006). Modeling The Metrics Of Lean, Agile And Leagile Supply Chain. *European Journal of Operational Research*, n.173, 211-225.

Agarwal, A., Shankar, R. & Tiwari, M.K. (2007). Modeling Agility Of Supply Chain. *Industrial Marketing Management*, 36,443-457.

Alimardani, M., Hashemkhani Zolfani, S. Aghdaie, MH. & Tamošaitienė, J. (2013). A Novel Hybrid SWARA and VIKOR Methodology For Supplier Selection In An Agile Environment. *Technological and Economic Development of Economy*, 19(3), 533-548.

Amy H.I. Lee. (2009). A Fuzzy Supplier Selection Model With The Consideration Of Benefits, Opportunities, Costs And Risks Expert Systems with Applications. 36 (2009) 2879–2893.

Asif Hasan, M., Shankar, R. & Sarkis, J. (2008). Supplier Selection In An Agile Manufacturing Environment Using DEA and ANP. *International Journal of Logistics Systems and Management*, Vol. 4, No. 5, 523-550.

Charnes, A., Cooper, W.W. & Rhodes, E., (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research* 2 (6), 429–444.

Chou, S.Y., & Chang, Y.H. (2008). A Decision Support System For Supplier Selection Based On A Strategy-Aligned Fuzzy SMART Approach. *Expert Systems with Applications*, 34(4), 2241–2253.