International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:10, No:8, 2016

Analytic Hierarchy Process Method for Supplier Selection Considering Green Logistics: Case Study of Aluminum Production Sector

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Abstract**—**The emergence of many environmental issues began with the Industrial Revolution. The depletion of natural resources and emerging environmental challenges over time requires enterprises and managers to take into consideration environmental factors while managing business. If we take notice of these causes; the design and implementation of environmentally friendly green purchasing, production and waste management systems become very important at green logistics systems. Companies can adopt green supply chain with the awareness of these facts. The concept of green supply chain constitutes from green purchasing, green production, green logistics, waste management and reverse logistics. In this study, we wanted to identify the concept of green supply chain and why green supply chain should be applied. In the practice part of the study an analytic hierarchy process (AHP) study is conducted on an aluminum production company to evaluate suppliers.

Keywords**—**Aluminum sector, analytic hierarchy process, decision making, green logistics.

I. Introduction

GREEN supply chain has become an important issue for all companies along with the depletion of natural resources and the pollution caused from disposals. Namely, supply chain management can be defined as a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements [1]. With the implementation of supply chain management companies have gained effective manufacturing and grown quickly. The increase in company sizes and numbers has also increased the use of natural resources. In fact, today brought the resources to the point of exhaustion. This dilemma is firstly explained by Hardin [2] as tragedy of commons. Besides the consumption of natural resources, the available resources also faced with the problem of contamination due to production wastes. Toxic chemicals, insoluble substances and other wastes damaged the natural cycles, renewal process and the balance of the nature by water, land and air.

With the disruption of natural balance and reduction of natural resources, an awareness has emerged and society began to be conscious. Awareness of the community and increasing competition companies are dragged into new pursuits. This situation has led businesses to manage their supply chain and production without harming the environment. At this point the green supply chain is noteworthy. Green supply chain is defined by Lo [3] as "including all environment-relevant practices, relationships among chain partners, and the minimization of the impact of firm practices on the natural environment through the use of recycled products/services".

This paper presents an AHP method to evaluate suppliers taking into account green logistics factors. The presented AHP is used for an aluminum company in Turkey.

II. Literature Review

Green logistics is a relatively new topic and researchers are increasingly studying it. Because of growing ecological concern and scarcity of natural resources, supply chain cannot be considered only forward movements of products and services but also reverse movements are important. Considering forward and reverse logistics operations, it is become very essential to integrate green logistics with supply chain.

Vahabzadeh et al. [4] offered a Fuzzy-VIKOR method using interval valued trapezoidal fuzzy numbers as a green decision making model in reverse logistics. First, the significant factors in environmental sound practices together with the main processes and recovery options in RL are identified. Second, the influences of each green environmental factor on each RL recovery option are analyzed and ranked.

Prakash et al. [5] studied reverse logistics adoption problem in electronics industry. A methodology is proposed based on fuzzy AHP and fuzzy technique for order performance by similarity to ideal solution (TOPSIS) to identify and rank the solutions of reverse logistics adoption to overcome its barriers.

Bouzon et al. [6] identified and evaluate the barriers for reverse logistics with regards to Brazil. Fuzzy Delphi method was used to obtain critical barriers and after AHP is used in order to obtain priority ranking of the barriers.

Prakash et al. [7] has aimed to evaluate and select reverse logistics partner. A combined model of Fuzzy AHP and Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) for selection of reverse logistics supplier. The proposed methodology is used for Indian Electronics Company.

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Senthil et al. [8] offered a hybrid method of AHP and TOPSIS for contractor evaluation and selection in third-party reverse logistics. AHP is used to obtain the initial weights and Fuzzy TOPSIS is used to get the final ranking.

Mani et al. used [9] an AHP based approach to select suppliers using social sustainability. At this methodology; equity, health, safety, wages, education, philanthropy, child and bonded labor as social sustainability indicators. The methodology is implemented in three case studies in India.

Felice and Petrillo [10] proposed a new application methodology to evaluate the best inventory strategy through the use of an integrated approach based on AHP and Simulation. Definitely AHP and simulation model is used in order to investigate and compare the behavior of the inventory control policies in terms of total supply chain costs.

III. Method

This research is done by a multi-criteria method namely AHP. AHP is created by Thomas Saaty between 1977 and 1994, has been introduced in the process by combining both qualitative and quantitative data used in the solution of complex decision problems to determine the best option [11]. The following steps are used in the analysis and calculation of the AHP as a decision-making problem.

Step 1. Identification of Decision-Making Problems

Decision-making problems consists of two parts. In the first part the aim is to determine decision points, and in the second part to determine criteria's and sub criteria's affecting these points.

The number of decision points (alternative) is represented by m, and the number of criterions is represented by n. Accurate determination of factors and making the detailed description of each factor is important to make a consistent comparison.

Step 2. The Creation of the Decision Matrices between Factors (Criterions)

For criteria's, comparison matrix is a square matrix of size nxn. The values on the diagonal is equal 1, that takes the value 1 when i = j. Because in this situation the criterion is compared with itself.

Comparing the criteria, it is considered how much important they are in each other and the comparison is done separately for each criteria. When comparing the criteria's severity ratings at Table I is used.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

TABLE I
Scale of Importance

Importance values	Description of values
1	Equally important
3	Moderately important
5	Strong critical
7	Very strong critical
9	Certain important
2,4,6,8	Intermediate values

Step 3. Determining the Percent Importance Distribution of the Factors

Column vectors which is constituting the comparison matrix are used to find the percent significance of the factors. As a result, n number and n component B column vector is generated.

$$B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ . \\ . \\ . \\ b_{n1} \end{bmatrix} \quad (2)$$

Using (3), B column vector is calculated:

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (3)$$

After that, the C matrix is formed when the column vector of n pieces B is brought together in a matrix format.

$$C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ c_{n1} & c_{n2} & \cdots & c_{nn} \end{bmatrix} \quad (4)$$

Then, the pieces are brought together when the B column vector in a matrix format, in this equation as shown, called the priority vector is calculated as the arithmetic mean of the components of the C matrix row W column vector (6) was obtained.

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n} \quad (5)$$

$$W = \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix} \quad (6)$$

Step 4. Measurement of Consistency in Criterion Comparison

Consistency is an important step for comparison between criterions. For example; if option M is 4 degree superior to option E, and option E is 1 degree superior to option D then option M should be 4 degree superior to option D.

Consistency Rate (CR) is calculated at AHP to determine if these comparisons are consistent. CR calculation at AHP is performed by comparing the number of criteria and (λ) coefficient named as basic value. For λ calculation, the matrix A is multiplied with the resulting matrix W and matrix D (7) is generated.

$$D = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix} \quad (7)$$

As an assessment factor, the basic values (E) are obtained using the corresponding elements of W column vectors which is calculated before and obtained D matrix. After λ basic value is calculated as stated in (9) which is the arithmetic average of these values.

$$E_i = \frac{d_i}{w_i} \quad i = 1,2,\dots,n \quad (8)$$

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \quad (9)$$

After calculating λ, Consistency Index (CI) was calculated utilizing (10):

$$CI = \frac{\lambda - n}{n-1} \quad (10)$$

Finally, CR values are calculated dividing by CI to Random Index (RI) (Table II) as stated in (11):

$$CR = \frac{CI}{RI} \quad (11)$$

TABLE II
RI VALUES

N	1	2	3	4	5	6	7	8	9	10
R	0	0	0,58	0,90	1,12	1,24	1,41	1,45	1,49	1,51

Pairwise comparison of the consistency ratio is smaller than 0.10 indicates that the consistent outcome of the transaction.

Step 5. Finding the Percent Importance Distribution of m Decision Point for Each Criterion

Percent importance distribution of decision points of the criterions are determined. For this, the procedure is repeated as the number of criteria. After the comparison process mx1 dimensional S column vectors (12) are obtained. S column vectors shows the percentage distribution of vectors according to the decision points.

$$S_i = \begin{bmatrix} s_{11} \\ s_{21} \\ . \\ . \\ . \\ s_{m1} \end{bmatrix} \quad (12)$$

Step 6. Finding Result Distribution of Decision Points

In this step, previously obtained, mxn dimensional K decision matrix (13) composed of n times mx1 dimensional S column vectors are generated.

$$K = \begin{bmatrix} s_{11} & s_{12} & \dots & s_{1n} \\ s_{21} & s_{22} & \dots & s_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ s_{m1} & s_{m2} & \dots & s_{mn} \end{bmatrix} \quad (13)$$

When the obtained the decision matrix multiplied with the initial W column vector L column vector (14) is obtained.

$$L = \begin{bmatrix} s_{11} & s_{12} & \dots & s_{1n} \\ s_{21} & s_{22} & \dots & s_{2n} \\ . & & & . \\ . & & & . \\ . & & & . \\ s_{m1} & s_{m2} & \dots & s_{mn} \end{bmatrix} x \begin{bmatrix} w_1 \\ w_2 \\ . \\ . \\ . \\ w_n \end{bmatrix} = \begin{bmatrix} l_{11} \\ l_{21} \\ . \\ . \\ . \\ l_{m1} \end{bmatrix} \quad (14)$$

As a result, obtained L column vectors have shown the percentage of criteria in order of importance.

A. Implementation Phase

AHP methodology can be widely implemented among different sectors. The research is conducted by one of the leading aluminum production companies of Turkey. The survey for AHP is done among 6 senior level employees from management, purchasing and logistics departments. The comparison of the alternatives is done by according to the defined criterions. The criterions are as follows:

- Recyclability
- Reusability
- Recycled materials
- Cost of energy

These factors are determined considering green supply chain at aluminum sector. Recyclability is the convenience of the aluminum material to be recycled. Reusability is convenience of the material to reuse it. Recycled material is indicating the recycled material when buying it. Lastly cost of energy is the consumed energy at production operations due to material and machines. The alternatives for these criteria are determined as quality, cost and lead time. Firstly, criteria are compared and therefore their comparative degrees are obtained. After that pairwise comparison of the alternatives is done.

IV. Results

The AHP model with the proposed factors is implemented at an aluminum production facility. The results of this study is obtained by calculating the results with MS Excel. At the tables given below percent degrees of criterions and alternatives can be found.

TABLE III
The Results for Recyclability Criterion

Recyclability	Percent Degree
Quality	57%
Cost	29%
Lead time	14%

TABLE IV
The Results for Reusability Criterion

Reusability	Percent Degree
Quality	16%
Cost	25%
Lead time	59%

TABLE V
The Results for Recycled Materials Criterion

Recycled Materials	Percent Degree
Quality	9%
Cost	67%
Lead time	24%

TABLE VI
The Results for Energy Cost Criterion

Energy Cost	Percent Degree
Quality	9%
Cost	31%
Lead time	60%

Considering recyclability and reusability criteria, the most important alternative is defined as lead time. When we consider recycled material criterion the most important alternative is cost. On the other hand, if we consider energy cost criterion the most important criterion is defined as lead time.

Finally, percent degrees of the criterions are calculated as given in Table VII. Final results show that recyclability is the most important criteria among the criterions and cost is the most important alternative among the alternatives.

TABLE VII
Percent Degrees of the Criteria

Recyclability	51%
Reusability	10%
Recycled materials	24%
Cost of energy	15%

TABLE VIII
Percent Degrees of the Alternatives

Quality	35%
Cost	38%
Lead time	27%

V. Conclusion and Suggestions

The world of natural resources, with depletion in a continuous manner, the need for green and eco-friendly supply chain is increasing. One of the biggest factor in the depletion of natural resources; clearly, the presence of the industry and irresponsible production in the facilities.

At this study, an evaluation and selection of green logistics criterions is done by experts from aluminum industry. The defined criterions can also be considered to evaluate the suppliers for similar sectors. Recyclability, reusability, recycled materials, cost of energy are determined as criterions. On the other hand, quality, cost and lead time are determined as alternatives. According to the results the criterions; recyclability, recycled materials, cost of energy, and reusability have the importance values respectively. Also the alternatives; cost, quality and lead time have the importance values respectively.

Considering green practices, some applications is proposed at the purchasing, production and logistics departments, and some of them mentioned below:

A waste management system is proposed at the production site and therefore waste materials can be recycled or eliminated by third-party waste collection companies.

For forklifts used in the production area of we offered to replace with electric forklifts. In terms of fuel costs and emissions a considerable amount of improvement can be provided.

Lastly, the application of reverse logistics is offered for aluminum materials coming from customers and the company itself. Because aluminum production from recycled aluminum reduces the amount of energy used and greenhouse gas 95%.

APPENDIX

Recyclability	9	8	7	6	**5**	4	3	2	1	2	3	4	5	6	7	8	9	Reusability
Recyclability	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Recycled materials
Reusability	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Recycled materials
Cost of energy	9	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	9	Recyclability
Cost of energy	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Reusability
Cost of energy	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Recycled materials

Fig. 1 The comparison of the criteria

						Recyclability												
Quality	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Cost
Quality	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Lead time
Lead time	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Cost
						Reusability												
Quality	9	8	7	6	5	4	3	2	1	**2**	3	4	5	6	7	8	9	Cost
Quality	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Lead time
Lead time	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Cost
						Recycled materials												
Quality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	9	Cost
Quality	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Lead time
Lead time	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Cost
						Cost of energy												
Quality	9	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	9	Cost
Quality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	**7**	8	9	Lead time
Lead time	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Cost

Fig. 2 The comparison of the alternatives with criteria

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