Aksiyomatik Tasarim ile Tedarikçi Seçimi: Bebek Mamasi Üretimi için Türkiye'de Bir Uygulama

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***Özet*—** Günümüz dünyasında araştırmacılar, üretim süreçlerini iyileştirmek ve daha düşük maliyet değerleri ile üretim yapmak için daha fazla çalışmaktadırlar. Bu amaçlara yönelik olarak birçok analitik ve sezgisel yaklaşım önerilmiştir. Bu çalışmada, Türkiye'de pazarın en büyüklerinden biri olan bir bebek maması üreticisi için tedarikçi seçim problemi ele alınmaktadır. Gıda üretimi insan hayatı için büyük önem taşımaktadır; bebek formüllerinin üretimi ve bu süreçle ilgili kararlarsa daha da önemlidir. Literatürde bu önemli probleme ilişkin bir çalışma bulunmamaktadır. Çözüm prosedürü boyunca, tedarikçi seçiminde hem nitel hem de nicel faktörlerin birlikte değerlendirilmesini sağlayan Bulanık Aksiyomatik Tasarım (AD) kullanılmıştır. Bu çalışma kapsamında, bulanık ve kesin bilgilerin birlikte değerlendirilebilmesine izin verdiği için, diğer Çok Kriterli Karar Verme yöntemlerine kıyasla daha avantajlı olan AD'nin ikinci aksiyomu olan bulanık bilgi aksiyomu kullanılmış ve tedarikçilere, hiyerarşik bir değerlendirme sunulmuştur.

***Anahtar Kelimeler*—** tedarik zinciri yönetimi, tedarikçi seçimi, çok kriterli karar verme, aksiyomatik tasarım.

Supplier Selection via Axiomatic Design: An Application in Turkey for Baby Formula Production

***Abstract*—** In today's world, researchers work harder in order to improve the manufacturing processes and to produce with lower cost values. Many different analytical and heuristic approaches are proposed for these aims. In this study, the supplier selection problem is taken into account for a baby formula producer, which is one of the largest ones of the market in Turkey. Food production is of high importance for human life; besides, production of baby formulas and the decisions related to this process are even more important. In the literature, there are no studies related to this major problem. Throughout the solution procedure, the problem is approached using Fuzzy Axiomatic Design (AD), which enables to use both qualitative and quantitative factors together in supplier selection problems. In the context of this work, the second axiom of AD, Fuzzy Information Axiom, which is more advantageous compared to other Multi Criteria Decision Making methods as it allows both fuzzy and certain information to be evaluated together, is used and a hierarchical evaluation is presented.

***Keywords*—** Supply chain management, supplier selection, multi criteria decision making, axiomatic design.

1. INTRODUCTION

During the early years of industrialization, companies had been producing necessary components on their own; however, as production systems became more complex, together with the increase in part quantity and new investments, the cost of this situation increased dramatically. As a result, the production of components that constitute the product are now mostly composed by outsourcing, and supply chains are formed. Due to global competition atmosphere and ever-changing customer claims, the demand from suppliers have also increased. Not only the cost of a product; but also the right time, right amount, right quality and best possible cost for the products have also become prominent. Because of these necessities, supplier selection and evaluation studies have begun. In supplier selection, besides many qualitative and quantitative criteria that affects the company, as there are many alternatives, it is very essential to establish criteria and solution method correctly and carefully in order to make the best choice suitable for the aim and criteria.

In addition to mathematical programming models [1], Multi Criteria Decision Making (MCDM) approaches are used commonly for supplier selection problems. Some of the methods that are often used in MCDM are Simple Additive Weighting, Weighted Product, Analytic Hierarchy Process (AHP), Revised Analytic Hierarchy Process, Analytic Network Process, ELECTRE, TOPSIS and Axiomatic Design (AD). AD technique and principles, developed by Suh [2] and have been improved rapidly over the last few years, has been used in many areas in designing products, systems, organizations and software. There is a literature review by Kulak et al. [3] in 2010 for using AD principles' application. Ched et al. [4] studied the best way of matching demand and suppliers in knowledge services. They used linguistic information determining expectation levels of both sides and a Fuzzy AD based methodology was developed in order to define the matching levels. Khandekar and Chakraborty [5] used Fuzzy AD principles for the selection of the non-traditional production technique to be used, as the demand for usage of these techniques increased. Khandekar and Chakraborty [6] developed a Fuzzy AD based methodology on personnel selection problem and used the suggested method on assignment of workers to a large-scale organization's service department. Kır and Yazgan [7] used Fuzzy AD in order to evaluate the obtained schedules' applicability on a one machine scheduling problem. In their study, it is predicted that real life limitations would be better reflected using Fuzzy AD in determining earliness and tardiness penalty costs. In another study that investigated green supply chain management applied in a Singapore located plastic manufacturer, Kannan et al. [8] sought a solution for supplier selection using Fuzzy AD. Khandekar and Chakraborty [9] practiced on Fuzzy AD principles on determining an industrial robot that would be used in an assembly line. Khandekar and Chakraborty [10] developed a Fuzzy AD based method for selecting a material handling equipment that would be used for a specific task. Khandekar et al. [11] proposed a Fuzzy AD based method that would be used on project selection performed at small hydro-power plants. Kulak et al. [12] made comparisons on medical imaging systems at a university hospital considering risk factors with Fuzzy AD. Maldonado-Macias et al. [13] applied Fuzzy AD in order to evaluate ergonomic compatibility of plastic molding machines. Vinodh et al [14] used Fuzzy AD deciding between various design alternatives of overflow valve in an automotive overflow valve manufacturing company. Weber et al. [15], again in a study conducted in automotive industry, used AD in designing production units that provide the variability and flexibility in answering the fluctuations in demand. In order to decide on a robot arm that would be used in production, Bahadir and Satoglu [16] made comparisons using TOPSIS method on a small-scale problem developing an AD based solution method and also tested the solution approach on a real production system. In a study that examined developing AD principle based decision processes in sustainable product development, Beng and Omar [17] reported that these principles can be helpful for designers or engineers in product improvement processes. Besides they claimed that Fuzzy AD approach could be helpful in green supplier selection and subjects like production optimization. Bilisik et al [18] investigated a location selection problem where maintenance and repair processes to be executed for Istanbul's mass transit system. In this study, criteria weights determined by Fuzzy AHP are used inside Fuzzy AD and alternative garage location priorities are identified. Gören and Kulak [19] expanded Fuzzy AD to be used in hierarchical decision problems and proposed a Hierarchical Fuzzy AD approach.

In today's world, supplier selection is an important decision problem and for food production companies this decision is relatively harder. When food sector is observed, aside from any physical production sector, due to high impact on human health, the criteria are changing and so it becomes impossible to ignore or rule out the deviations from such criteria. Baby formula manufacturing, besides its importance on growing up healthy generations, is a very rare problem in literature. The one and the only study on this topic has investigated supplier evaluation for a company that produces baby formula in 1996 by Weber [20]; using Data Envelopment Analysis, they evaluated each of the 6 suppliers by comparing them to the best supplier on the market.

In this study, second axiom of AD, the Information Axiom, which allows evaluating both qualitative and quantitative factors on supplier selection problem of a baby formula producing company has been used and a choice has been made between alternative suppliers by obtaining ranges that have been stated with numerical and linguistic variables for the stated criteria. The problem has been evaluated with the results obtained using Fuzzy AD. The main contribution of this study is that this is the first study using Fuzzy AD methodology on selecting the best supplier for a baby formula production company. As another difference; besides there is a comparison between suppliers, a hierarchical evaluation is presented and by doing so, a decision opportunity is given to the decision maker between alternatives.

This paper is organized as follows: In the following section, the executed Fuzzy Set Theorem and Fuzzy AD theorems are explained. In Section 3, there is an application of established hierarchical supplier selection model on a baby formula producer. In Section 4, the study is evaluated and suggestions are given by interpreting the obtained solution results.

2. FUZZY AXIOMATIC DESIGN

MCDM techniques aim to enable decisions between alternatives that are defined by more than one criteria and these kind of problems are often seen in engineering decisions. In this study the investigated problem is the supplier selection for a baby formula production company. The company tries to decide between suppliers by selecting the most financially advantageous one while regarding the current health restrictions by thinking the effect of the product on baby health. For this problem, 7 main criteria are determined: lead time, raw material quality, price, certificates and experience, communication, payment method, delivery time. According to these criteria, supplier selection is performed among 6 possible suppliers using Fuzzy AD. In the decision making process, situations with certain (qualitative) information are observed to be better than situations with uncertain (quantitative) information. However in real life, decision makers often face fuzzy data and qualitative evaluation is impossible to do [21]. In order to deal with such circumstances, Fuzzy Set Theorem was proposed by Zadeh in 1965 [22]. Fuzzy data may include fuzzy sets and/or numbers, or linguistic terms. In case it consists of linguistic terms, the data has to be converted into fuzzy numbers first. After this, all fuzzy numbers (or sets) are converted into crisp data. On the equation below the notation of triangular fuzzy number is given and the schematic construction of membership functions belonging to linguistic variables that are used to convert non-numerical factors into numbers are shown in Figure 1 [23,24].

Each expert gives his/her evaluation as one of the possible options: a score between 0 and 10, a score range, a linguistic variable or an approximate value. Since very low number of decisions that can provide a quantitative evaluation could be found, Fuzzy MCDM techniques are important and in this study, a MCDM solution is searched using Fuzzy AD.

$$\mu(x) = \begin{Bmatrix} \frac{x-c}{a-c}, & c \leq x \leq a, \\ \frac{b-x}{b-a}, & a \leq x \leq b, \\ 0, & otherwise. \end{Bmatrix} \quad (1)$$

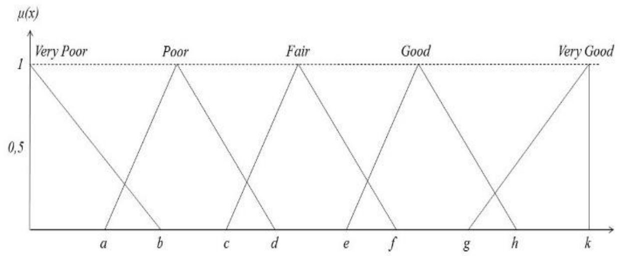

Figure 1. Numerical representation for intangible factors

AD is a design method proposed by Suh in order to bring scientification to the design area for products, systems and processes [2]. Final aim in AD is to obtain a scientific establishment in order to improve design activities, by providing a theoretical foundation grounded on logical and rational thought processes and tools [25]. One of the most important aspects of AD principles is that it allows not only to determine the best alternative to be chosen from a certain set of criteria but also to choose the best suitable alternative [8].

Within design by axioms, the most important concept is the presence of axioms. These axioms are as follows:

1. Independence Axiom: To continue the independence of functional requirements.
2. Information Axiom: To minimize the information content.

Independence Axiom states that the independence of functional requirements, which are defined as the minimum number of independent functional requirements that characterize the design aims, should always be protected. Information Axiom proposes that amongst design alternatives that provide Independence Axiom, the best design is the one which has the minimum information content. Investigating the literature, it can be seen that Information Axiom is used as an MCDM tool in selecting the most suitable system while selecting designed systems such as equipment, logistics companies, modern production or service systems [26]. Information is expressed by I_i information content and related to given functional requirements' (FR) actualization probability. For a given FR, I_i value is calculated as follows:

$$I_i = log_2(\frac{1}{p_i}) \quad (2)$$

where, p_i expresses the probability to reach FR_i. In design process, the probability to reach determined target is defined based in tolerance values with what the designer wants to reach (design range) and system capabilities (system range). As shown in Figure 2, the intersection of design range and system range occurs as the common range where acceptable solution will be found.

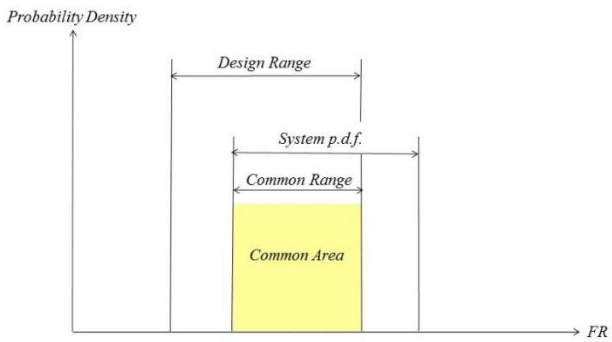

Figure 2. Design range, system range, common range and probability density function (p.d.f.) of a functional requirement (FR)

For a FR with normal probability density function, p_i value is calculated as follows:

$$p_i = (\frac{Common\ range}{System\ range}) \quad (3)$$

Here, the common range can be seen as the harmony between design range and system range. Expectation level can be evaluated as design range while system range can be evaluated as current range. If done so, information content can be calculated as follows:

$$I_i = \log_2\left(\frac{System\ range}{Common\ range}\right) \quad (4)$$

In case FR_i is a continuous random variable, p_i is calculated as follows:

$$p_i = \int_{dr^l}^{dr^u} p_s(\mathrm{FR}_i).d\mathrm{FR}_i \quad (5)$$

where $p_s(FR_i)$ determines the probability density function for FR_i and dr^l and dr^u determines the lower and upper limits for design range. This equation defines the design's reaching its determined target probability by applying system's probability density function to whole design. As it can be seen from Figure 3, common range area (A_{cr}) is equal to probability p_k [25]. In this case, as A_{cr} points to the area under common range, the information content can be calculated as follows:

$$I_i = \log_2\left(\frac{1}{A_{cr}}\right) \quad (6)$$

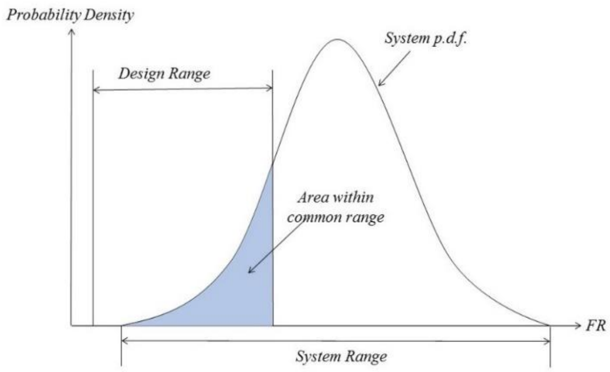

Figure 3. Design range, system range, common range and p.d.f. of an FR

Fuzzy AD is developed by Kulak and Kahraman [23, 27] related to the multi criteria decision making problem solving where linguistic information is present. In circumstances where system and design ranges are expressed linguistically, uncertain data situations may occur. In those cases, system and design ranges are expressed with linguistic terms denoted by fuzzy numbers. Within Fuzzy AD, triangular or trapezoid fuzzy membership functions are used in situations where probability density function is certain and range values are given linguistically. As a result of this, as can be observed in Figure 4, common range is the intersection of triangular fuzzy area of system range and triangular fuzzy area of design range. For this case information content is calculated as follows [25]:

$$I = \log_2\left(\frac{Triangular\ fuzzy\ area\ of\ system\ design}{Common\ area}\right) \quad (7)$$

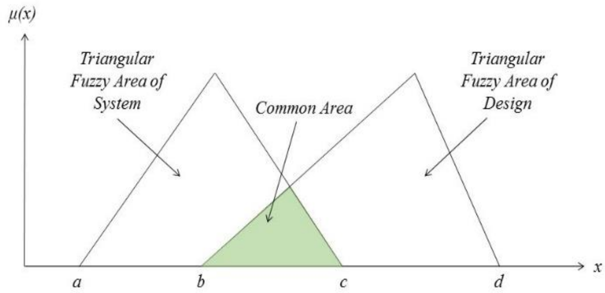

Figure 4. The common range of system and design ranges.

3. HIERARCHICAL SUPPLIER SELECTION FOR A BABY FORMULA MANUFACTURER

In this study, the problem of selecting suppliers for a baby food manufacturing company located in Ankara, for acquiring important raw materials required for baby food was investigated and a choice has been made amongst alternative suppliers by developing a hierarchical supplier selection model with Fuzzy AD method.

As a result of interviews with the company's department of purchasing management, the most important criteria that affects supplier selection for the manufacturer are determined under 7 main titles. These are;

1. Lead Time: Expresses the time from raw material order issue to the raw material reaching the company.
2. Raw Material Quality: Expresses the quality condition requirements stated in baby food restrictions.
3. Price: Expresses that the supplies should be obtained both in good quality and low prices.
4. Certificates and Experience: Since baby food manufacturing requires a thorough and delicate production, the supplier companies are checked for necessary certifications. Furthermore, this title expresses the experience of supplier in this subject and how long the supplier company has been producing the product.
5. Communication: Expresses the strong/weak relationship between supplier and the production company.
6. Payment Method: Expresses which of the following methods is used: credit, cash or wire-transfer.
7. Delivery Time: Expresses delivery on time.

According to these criteria in order to determine the best supplier, Fuzzy AD is used. Following steps are taken in the study:

Step 1. Evaluation of determined criteria by experts
Step 2. Conversion of obtained linguistic information into triangular fuzzy numbers

Step 3. Combining of expert evaluations to obtain criteria based results.
Step 4. Determination of FRs.
Step 5. Calculation of information content.
Step 6. Ranking of alternatives.

3.1. The Application of Fuzzy AD Approach

In order to apply Information Axiom of AD, first the Independence Axiom of AD should be provided. In this study, the FRs necessary for alternatives, or namely the determined criteria are independent from each other. To calculate the information contents of each and every alternative, FR design ranges should be determined. Since a lot of raw materials are necessary for production and packaging of a baby food, the flour is investigated in detail and supplier selection is made on this raw material. For this aim, as a result of study with the collaboration of managers in the company, the design ranges determined for FR's and system ranges realized by supplier companies are listed in Table 1 and Table 2.

Table 1. Design range data

CRITERIA	DESIGN RANGE
Lead time (LT)	(2, 10)
Raw material quality (RM)	(13, 25, 25)
Price (P)	(0.9, 1.4)
Certification and experience (CE)	(15, 23, 25)
Communication (C)	(8, 16, 23)
Payment method (PM)	(16, 25, 25)
Delivery time (DT)	(9, 22, 25)

Table 2. System range data for the suppliers

SUPPLIER	LT	RM	P	CE	C	PM	DT
1	2 - 5	Very Good	1.3 - 1.5	Very Good	Very Good	Good	Good
2	7 - 10	Good	1.2 - 1.5	Very Good	Good	Very Good	Very Good
3	3 - 5	Fair	1.25 - 1.30	Fair	Perfect	Very Good	Very Good
4	18 - 23	Poor	0.75 - 1	Poor	Poor	Very Good	Poor
5	8 - 12	Very Poor	1 - 1.3	Good	Good	Very Good	Good
6	9 - 15	Fair	0.9 - 1.2	Fair	Good	Very Good	Very Good

Since some criteria cannot be expressed as numerical values, linguistic variables are used (see Table 1). To convert these data into numerical data, the membership functions of given linguistic variables showed in Figure 5 are used. According to this data; if a supplier is expressed as "very poor" it gets (0, 0, 6) value, if it is expressed as "poor" it gets (3, 7, 11) value, if it is expressed as "fair" it gets (8, 12, 16) value, if it is expressed as "good" it gets (13, 17, 21) value and if it is expressed as "very good" it gets (18, 25, 25) value.

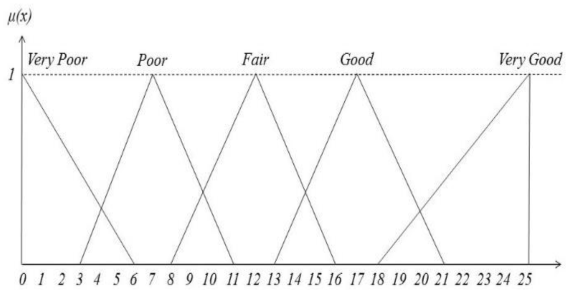

Figure 5. Triangular fuzzy numbers for intangible factors

To obtain common areas of design range and supplier companies, GeoGebra software is used. Figure 6 shows the design, system and common areas of the suppliers where design range for raw material quality criteria is expressed with the triangular fuzzy function (13, 25, 25). Table 3 lists the system expressions realized by suppliers and their triangular fuzzy function values. System areas of suppliers are listed in Table 4.

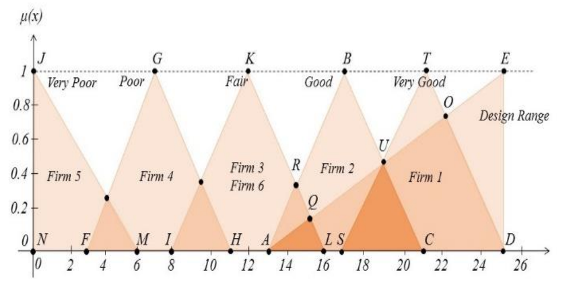

Figure 6. Design range data for raw material quality criterion

For lead time criteria, the company wants a design range changing between (2, 10) hours. Firm 1 gives 2 to 5 hours, Firm 2 gives 7 to 10 hours, Firm 3 gives 3 to 5 hours, Firm 4 gives 18 to 23 hours, Firm 5 gives 8 to 12 hours and Firm

6 gives 9 to 15 hours. Common and system ranges are calculated and shown in Figure 7.

Table 3. System range data for the suppliers and triangular fuzzy function values

SUPPLIER	DATA	FUZZY FUNCTION VALUES
1	Very Good	(18,25,25)
2	Good	(13,17,21)
3	Fair	(8,12,16)
4	Poor	(3,7,11)
5	Very Poor	(0,0,6)
6	Fair	(8,12,16)

Table 4. System areas for the suppliers

SUPPLIER	AREA	COMMON RANGE
1	3,5 unit^2 (area SED)	3,5 unit^2 (area SED)
2	4 unit^2 (area ABC)	2 unit^2 (area AUC)
3	4 unit^2 (area IKL)	0,28 unit^2 (area AQL)
4	4 unit^2 (area GHF)	10^{-5} (penalty coefficient) *
5	3 unit^2 (area JMN)	10^{-5} (penalty coefficient) *
6	4 unit^2 (area IKL)	0,28 unit^2 (area AQL)

* Since they have no common areas with the design range, penalty coeffecients are applied to Supplier 4 and Supplier 5.

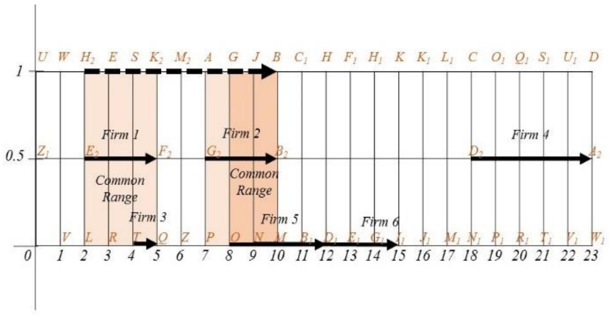

Figure 7. System, design and common ranges of the suppliers for lead time criterion

Since lead time is a qualitative value and is represented by a linear range, uniform probability density function is used. For example, system probability distribution function of Supplier 1 is between 2 and 5. This leads to the common range, which is the intersection area between design range and system range, to cover the space between 2 and 5.

The information in Figure 7 is substituted in Equation 4 and information contents for lead time are calculated. These calculations are performed for each of the seven criteria. After these calculations information content related to companies are calculated and listed in Table 5.

Table 5. Information contents for suppliers

	I_{LD}	I_{HM}	I_P	I_{CE}	I_C	I_{PM}	I_{DT}	Σ I
DESIGN RANGE	(2; 10)	(13; 25; 25)	(0,9; 1,4)	(15; 23; 25)	(8; 16; 23)	(16; 25; 25)	(9; 22; 25)	Σ
SUPPLIER 1	0	0	1	0,51	2,07	2,05	0,255	5.885
SUPPLIER 2	0	1	0,58	0,51	0,12	0	0,514	2,724
SUPPLIER 3	0	3,83	0	6,32	2,07	0	0,514	12,734
SUPPLIER 4	18,93	18,60	1,32	18,6	3,28	0	6,94	67,67
SUPPLIER 5	1	18,19	0	1,28	0,12	0	0,255	20,845
SUPPLIER 6	2,58	3,83	0	3,83	0,9175	0	0,514	11,674

When the information listed in Table 5 is investigated, Supplier 2 is selected as the best suitable supplier as it has the minimum information content. As alternatives to Supplier 2; for 2nd priority Supplier 1, for 3rd priority Supplier 3, for 4th priority Supplier 6, for 5th priority Supplier 5 and for 6th priority Supplier 4 is recommended to be selected.

4. CONCLUSION

During recent years, there have been many studies as a result of the effort to lower production costs. In order to obtain an advantageous position in the global market, it is essential to correctly evaluate the limited conditions. It is also very important to make right decisions in each and every step within the process which starts with improving purchasing process, continuing with production and leading to another production process with recycling. A correct production process can be initiated by correctly evaluating the suppliers in purchasing process. A safe and low cost purchasing can be established by working with suppliers that meet the necessary criteria. In this study, the supplier selection and evaluation for a baby food producing company is investigated, for which more delicate decision making is required. Criteria that affect the decision are specified. AD method, which is a MCDM method that can take qualitative and quantitative evaluation, is deployed in order to make a decision between alternative suppliers. In order to achieve this, functional requirements are determined for each criteria and suppliers are ranked by calculating data content. It is recommended to work with the supplier with minimum data content. The hierarchical supplier selection model that is developed in this study can be used together with the Fuzzy Information Axiom when fuzzy and unclear information is encountered. Doing all calculations manually prolongs the time to figure out the results. This is considered as a risk since it would extend the time to avoid potential mistakes.

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