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# A fuzzy MCDM approach to determine the most influential logistic factors

## *En etkili lojistik faktörleri belirlemek için bulanık bir ÇKKV yaklaşımı*

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# En Etkili Lojistik Faktörleri Belirlemek İçin Bulanık Bir ÇKKV Yaklaşımı

*Araştırma Makalesi / Research Article*

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## ÖZ

Malzeme yönetimi sanatı; lojistik işletmelerin etkinlik ve verimliliğinde önemli bir rol oynar. En etkili lojistik faktörleri belirlemek çok önemlidir; çünkü lojistik maliyetler toplam işletme maliyetinin %30'una tekabül etmektedir. Bu çalışmada lojistik firmaların başarısını etkileyen maliyet, hız, güvenilirlik, müşteri memnuniyeti, dağıtım kanalı, firma imajı, çevre dostu olma ve teknolojik yeniliklere açık olma gibi faktörler incelenmiş ve sıralanmıştır. Faktörleri sıralamak için Pisagor Bulanık (PF) kümeleri, üçgensel bulanık sayılar ve Analitik Hiyerarşi Prosesi (AHP) temelinde üç farklı yaklaşım önerilmiştir. Literatüre yeni girmesine rağmen, Pisagor bulanık kümeleri belirsizlik hesaplamasında yaygın olarak kullanılmaktadır. AHP, F-AHP ve PF-AHP yöntemleri uygulanarak en etkili üç lojistik faktörü maliyet, hız ve güvenilirlik olarak belirlenmiştir, ancak faktör ağırlıkları farklıdır. AHP, F-AHP ve PF-AHP sonuçları arasındaki farklılıkların değerlendirmelerin kesin değerlerle yapılması, dilsel ifadelerin kullanılması ya da üyelik derecesi koşulunun sağlanıp sağlanamamasından kaynaklandığını düşünmekteyiz. Bunun yanında Türkiye'deki ilk 10 lojistik firma bu kriterlere göre puanlanarak sıralanmıştır. Lojistik firmaların faktörlere göre yapılan sıralarının ekonomik büyüklüklerinden farklı olduğu görülmüştür.

**Anahtar Kelimeler:** Lojistik, pisagor bulanık sayılar, AHP, bulanık-AHP, ÇKKV.

## A Fuzzy MCDM Approach to Determine the Most Influential Logistic Factors

### ABSTRACT

The art of managing materials; logistics play a crucial role in efficiency and productivity of companies. It is very significant to determine most influential logistic factors since logistic costs account for 30% of total company costs. The factors affecting success of logistic enterprises such as cost, speed, reliability, customer satisfaction, distribution channel, company image, environmental friendliness and technological innovations are investigated and ranked in this study. Three different approaches based on Pythagorean Fuzzy sets, triangular fuzzy numbers and Analytic Hierarchy Process is offered for ranking these factors. Although it has been introduced to literature recently, the pythagorean fuzzy sets are widely employed in calculating uncertainty. The three most influential logistic factors are revealed as cost, speed and reliability, respectively by employing AHP, Fuzzy AHP and Pythagorean Fuzzy AHP, however factor weights are different. We think that the differences with in the AHP, F-AHP and PF-AHP results may stem from expressing evaluations in exact values, linguistic terms or in some cases it may be related to fulfilling the condition of membership and non-membership. Furthermore, top 10 logistic firms in Turkey are scored and ranked to these factors. Logistics, Pythagorean fuzzy sets, AHP, Fuzzy AHP, MCDM.

**Keywords:** Logistics, pythagorean fuzzy sets, AHP, fuzzy AHP.

### 1. INTRODUCTION

Logistics provide the efficient movement of supplies to the customers and plays a vital role in satisfying customer demands in time and at the lowest possible cost. In logistics, transportation costs, occupying more than one-third of logistic costs, influence the efficiency of whole production processes from manufacturing to delivery to final consumers and returns.

A good transportation system brings benefits to service quality and company competitiveness. Logistic costs account for 30% of the total company costs. A management perspective on logistics activities is required [1]. For that reason, it is very significant to

determine most influential logistic factors in company's supply chain operations. Here, Multi Criteria Decision Making (MCDM) methods based on Pythagorean Fuzzy (PF) sets, triangular fuzzy numbers and Analytic Hierarchy Process (AHP) can be easily applied as a decision support tool to rank these factors and determine the most influential one. Utilization of PF sets in MCDM is not quite new. However, it is difficult to find a research in the literature focused on logistic factors using PF numbers, triangular fuzzy numbers and AHP. Kumru and Kumru [2] employed an AHP model in selecting the most suitable way of transportation between two given locations in Turkey for a logistic company.

Logistic activities have always enlisted interest of researchers and firms in order to improve services and reduce costs. Different approaches were offered for

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evaluating performance of logistic activities. Past performance records were frequently used as a single evaluation dimension, but it is not sufficient for a comprehensive evaluation [3-8]. A number of papers were determined significant logistic resources and examined their effects on logistic performance with respect to Resource-Based View (RBV) theory, which believes that the success of logistic activities is based on unique and valuable resources of companies [9-13]. The RBV theory considers company resources in two categories, which are tangible resources, e.g technology and physical resources and intangible resources, e.g. management expertise, relational and structure resources. However, large number of conflicting criteria had to be considered and analyzed in all of the aforementioned studies. Determining the most influential factors for success of logistics enterprises can be handled as an MCDM problem. Making decisions in the presence of multiple, usually conflicting, logistic criteria and finding the best option from all of the feasible alternatives is only possible with MCDM tools [14].

The purpose of this paper is to present a fuzzy analytical approach for evaluating logistic factors and companies. This paper is one of a kind on considering logistic factors as an MCDM problem which employs pythagorean fuzzy numbers and presents a holistic view. Purpose and originality of the study are explained in this section. We also briefly present the literature here.

The rest of the paper is organized as follows. Methodology of the research is presented in Section-2. AHP, F-AHP and PF sets and PF-AHP steps are briefly explained in this section with general features and basic notions. Section-3 is devoted to evaluation of logistic factors and discussions of results. Illustrative examples for the decision models together with comparative step-by-step analysis are given. The most influential logistic factors are revealed as cost, speed and reliability, respectively. The sequence of factors varies in AHP, F-AHP and PF-AHP results. The conclusions are made in Section 5 and suggestions for future work are explained.

In logistics, main cost is the payments made for the transportation between two points that may be affected by site of the company. Another criterion to be considered for success of logistics is speed related to duration between two sites where materials are transported. Consistently meeting promised delivery times and fulfilling service requirements for shipper's consignments determines the reliability of logistic services. Considering transportation modes, reliability is good for highway and railway and it is related to flexibility [15]. Offering convenient schedules or allowing to non-specific extra pick-up and deliveries, determines the flexibility of transportation modes and logistic enterprises.

Satisfying customer demands in time and at the lowest possible cost is one of the main objectives of logistics. Customer satisfaction is greatly affected by distribution channels, which are highway, railway, waterway, pipeline and airway. They have different advantages as well as disadvantages in terms of reduced cost, increased agility and service. Air quality, reducing greenhouse gas emissions, noise, waste are the issues concerned with environmental friendliness. Due to aforementioned explanations factors such as cost, speed, reliability, customer satisfaction, distribution channel, company image, environmental friendliness, being open-minded to technological innovations (industry 4.0 applications, etc.) are selected for evaluation. In this study a fuzzy MCDM approach based on PF sets, triangular fuzzy numbers and AHP is presented to evaluate logistic factors and rank logistic enterprises.

Yager introduced pythagorean fuzzy sets to the literature, since in some cases, intuitionistic fuzzy sets unable to capture the condition for degrees of membership and non-membership greater than 1 [16]. Pythagorean fuzzy sets are employed in many different applications. Yücesan and Kahraman (2019) employed PF-AHP for risk assessment in hydroelectric power plants [17]. Gül and Ak, (2018) calculated the importance levels of parameters by a  $5 \times 5$  matrix method with the help of the PF-AHP [18].

İlbarhar et al. (2018), proposed an integrated risk assessment approach which includes Pythagorean Fuzzy Proportional Risk Assessment, Fine Kinney, PF-AHP and a fuzzy inference system [19]. They applied this approach to the risks of an excavation process in a construction yard. Karasan et al (2018) proposed a new PF-AHP for site selection [20]. Mete (2018) stated that pythagorean fuzzy sets cover vagueness in a more suitable way and proposed an FMEA-based AHP-MOORA integrated approach under pythagorean fuzzy sets for assessing occupational risks in a natural gas pipeline construction project [21]. Gül (2018) developed a two-phase approach for risk assessment which includes PF-AHP and Fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje (F-VIKOR) [22]. Gül (2018) evaluated a gun and rifle barrel external surface oxidation and colouring unit with this method [22]. PF numbers were integrated with various MCDM techniques, e.g. TOPSIS [23-25], VIKOR [26, 27] PROMETHEE [28] and CODAS [29] in the literature.

**Table 1.** Linguistic Scale [43]

| Linguistic scale for importance     | Triangular fuzzy scale |
|-------------------------------------|------------------------|
| Just equal (JE)                     | (1, 1, 1)              |
| Equally important (EI)              | (1/2, 1, 3/2)          |
| Weakly more important (WMI)         | (1, 3/2, 2)            |
| Strongly more important (SMI)       | (3/2, 2, 5/2)          |
| Very strongly more important (VSMI) | (2, 5/2, 3)            |
| Absolutely more important (AMI)     | (5/2, 3, 7/2)          |

**2.MATERIAL and METHOD**

**2.1. AHP and Fuzzy AHP**

AHP was developed by Thomas L. Saaty in 1977 to solve complex multi criteria decision making problems [30]. AHP was employed to problems in various areas, such as aviation [31-33], equipment and supplier selection [34-35], energy [36-38], investment [39], facility planning [40] and agriculture [41]. However, decision makers feel more comfortable when they express their evaluation in linguistic terms in place of exact values during decision-makings [42]. Fuzzy numbers can be explained with the confidence interval and are defined over a fuzzy subset of real numbers. In this study, the triangular fuzzy numbers in Table 1 were used during the evaluations [43].

Factor weights were determined by taking geometric means and alpha-cut method was employed for the defuzzification of fuzzy numbers.

**2.2. Pythagorean Fuzzy Sets and PF- AHP**

Three basic representations for pythagorean membership grades are provided in the related literature [16]. The first representation of PF membership is  $(a, b)$  satisfying the conditions that  $a \in [0, 1], b \in [0, 1]$  and  $a^2 + b^2 \leq 1$ .

The second one is the polar coordinates  $(r, \theta)$  satisfying conditions that  $r \in [0, 1]$  and  $\theta \in \left[0, \frac{\pi}{2}\right]$ . Finally, last representation of PF membership grade is  $(r, d)$  close to the second one satisfying the conditions that  $r \in [0, 1]$ .

$\theta \in \left[0, \frac{\pi}{2}\right]$  and  $d = 1 - \frac{2\theta}{\pi}$ . Their relationship is that  $a^2 + b^2 = r^2, a = r \cos(\theta), b = \sin(\theta)$ .

A fuzzy subset having these pythagorean membership grades referred as a PFS by Yager [16].

A PFS is defined as follows.

$$\tilde{P} = \left\{ x, P(\mu_p(x), v_p(x)) \mid x \in X \right\}, \tag{1}$$

where the function  $\mu_p : X \rightarrow [0, 1]$  defines the degree of membership and  $v_p : X \rightarrow [0, 1]$  defines the degree of

non-membership of the element  $x \in X$  to P respectively and for every  $x \in X$  it holds that

$$0 \leq (\mu_p(x))^2 + (v_p(x))^2 \leq 1 \tag{2}$$

For any PFS and  $\tilde{P} \ x \in X, \pi_p(x) = \sqrt{1 - \mu_p^2(x) - v_p^2(x)}$  is called the degree of indeterminacy of  $x$  to  $\tilde{P}$ .

Given three PFNs  $P_1 = P(\mu_{p_1}, v_{p_1}), P_2 = P(\mu_{p_2}, v_{p_2})$  and  $P = P(\mu_p, v_p)$

Yager defined the basic operations on them which can be described as follows [16]:

$$P_1 \cup P_2 = P \left\{ \max \{ \mu_{p_1}, \mu_{p_2} \}, \min \{ v_{p_1}, v_{p_2} \} \right\}. \tag{3}$$

$$P_1 \cap P_2 = P \left\{ \min \{ \mu_{p_1}, \mu_{p_2} \}, \max \{ v_{p_1}, v_{p_2} \} \right\}. \tag{4}$$

Some mathematical operators for PFNs are defined as follows.

$$\tilde{P}_1 \oplus \tilde{P}_2 = P \left( \sqrt{\mu_{p_1}^2 + \mu_{p_2}^2 - \mu_{p_1}^2 \mu_{p_2}^2}, v_{p_1}, v_{p_2} \right) \tag{5}$$

$$\tilde{P}_1 \otimes \tilde{P}_2 = P \left( \mu_{p_1}, \mu_{p_2}, \sqrt{v_{p_1}^2 + v_{p_2}^2 - v_{p_1}^2 v_{p_2}^2} \right). \tag{6}$$

$$\lambda \tilde{P} = P \left( \sqrt{1 - (1 - \mu_p^2)^\lambda}, (v_p)^\lambda \right), \lambda \geq 0 \text{ and } \lambda \in R. \tag{7}$$

Zhang and Xu (2014) defined the Euclidean distance between two PFNs as in the following equation [44]:

$$d(\tilde{P}_1, \tilde{P}_2) = \frac{1}{2} \left( \left| \mu_{p_1}^2 - \mu_{p_2}^2 \right| + \left| v_{p_1}^2 - v_{p_2}^2 \right| + \left| \pi_{p_1}^2 - \pi_{p_2}^2 \right| \right) \tag{8}$$

The Taxicab distance between two PFSs is defined by equation below;

$$T(\tilde{P}_1, \tilde{P}_2) = \left( \left| \mu_{p_1} - \mu_{p_2} \right| + \left| v_{p_1} - v_{p_2} \right| + \left| \pi_{p_1} - \pi_{p_2} \right| \right). \tag{9}$$

Let  $p_1 = (\mu_1, v_1)$  and  $p_2 = (\mu_2, v_2)$  be two Pythagorean fuzzy number and  $\rho > 0$ . The following operations are presented for Pythagorean fuzzy number [44, 45]

$$\tilde{P}_1 \circ \tilde{P}_2 = P \left( \sqrt{\frac{\mu_1^2 - \mu_2^2}{1 - \mu_2^2}}, \frac{v_1}{v_2} \right) \text{ if } \mu_1 \geq \mu_2, v_1 \leq \min \left\{ v_2 \frac{v_2 \pi_1}{\pi_2} \right\} \quad (10)$$

$$\frac{\tilde{P}_1}{\tilde{P}_2} = \left( \frac{\mu_1}{\mu_2}, \sqrt{\frac{v_1^2 - v_2^2}{1 - v_2^2}} \right) \text{ if } \mu_1 \leq \min \left\{ \mu_2 \frac{\mu_2 \pi_1}{\pi_2} \right\}, v_1 \geq v_2 \cdot (11)$$

Pythagorean fuzzy sets can be defined as the general form of the intuitionistic fuzzy sets in which intuitionistic fuzzy sets cannot handle the ambiguity of data [31].

**Definition (1)** Let a set X be a universe of discourse. A Pythagorean fuzzy set P is an object having the form [22]:

$P = \{ \langle x, P(\mu_p(x), v_p(x)) \rangle \mid x \in X \}$  where

$\mu_p(x) : X \rightarrow [0, 1]$  degree of membership

$v_p(x) : X \rightarrow [0, 1]$  degree of non-membership

of the element  $x \in X$  to P. For every  $x \in X$ , the following holds:  $0 \leq \mu_p(x)^2 + v_p(x)^2 \leq 1$

Steps of PF-AHP: These steps are taken from Gül (2018)'s paper [22]:

**Step 1.** Pairwise comparison matrix  $A = (a_{ik})_{m \times m}$  is determined with respect to the linguistic evaluations of experts using the scale offered by Ilbahar et al [19].

**Step 2.** The difference matrixes  $D = (d_{ik})_{m \times m}$  between the lower and upper values of the membership and non-membership functions are revealed by employing Eq. (12) and (13).

$$d_{ikL} = \mu_{ikL}^2 - v_{ikU}^2 \quad (12)$$

$$d_{ikU} = \mu_{ikU}^2 - v_{ikL}^2 \quad (13)$$

**Step 3.** The interval multiplicative matrix  $S = (s_{ik})_{m \times m}$  is found with respect to Eq.(14) and Eq.(15):

$$S_{ikL} = \sqrt{1000^{d_{ikL}}} \quad (14)$$

$$S_{ikU} = \sqrt{1000^{d_{ikU}}} \quad (15)$$

**Step 4.** The determinacy value  $\tau = (\tau_{ik})_{m \times m}$  is determined with the help of Eq. (16)

$$\tau_{ik} = 1 - (\mu_{ikU}^2 - \mu_{ikL}^2) - (v_{ikU}^2 - v_{ikL}^2) \quad (16)$$

**Step 5.** The determinacy degrees are multiplied with  $S = (s_{ik})_{m \times m}$  matrix weights  $T = (t_{ik})_{m \times m}$  using Eq.(17) :

$$t_{ik} = \left( \frac{S_{ikL} + S_{ikU}}{2} \right) * \tau_{ik} \quad (17)$$

**Step 6.** Each normalized priority weight  $w_i$  is calculated by using Eq. 18.

$$w_i = \sum_{k=1}^m t_{ik} / \sum_{i=1}^m \sum_{k=1}^m t_{ik} \quad (18)$$

The readers who wants to learn more information about AHP, fuzzy AHP and Pythagorean fuzzy AHP can benefit from [19, 22] respectively.

### 3. RESULTS AND DISCUSSION

In this part of the study, evaluation matrices and results of the applied methods are given in Table 2, Table 3 and Table 4 respectively. The criteria handled in this study are cost (C1), speed (C2), reliability (C3), customer satisfaction (C4), distribution channel (C5), company image (C6), environmental friendliness (C7), technological innovations and logistic 4.0 (C8).

The method followed in F-AHP can be briefly defined as employing geometric means of the rows and the alpha-cut method for the defuzzification.

Results of Fuzzy AHP and weightst are presented in Table 2. The most important criterion is revealed to be reliability (C3) with respect to F-AHP results. The sequence of most influential logistic factors to F-AHP is presented in Table 2 as reliability (C3), speed (C2), cost (C1), customer satisfaction (C4), distribution channel (C5), company image (C6), technological innovations and logistic 4.0 (C8) and environmentally friendliness (C7).

**Table 2.** Results of F-AHP

|    | C1      | C2          | C3            | C4          | C5          | C6            | C7          | C8          | Weights |
|----|---------|-------------|---------------|-------------|-------------|---------------|-------------|-------------|---------|
| C1 | (1,1,1) | (1/2,1,3/2) | (2/5,1/2,2/3) | (3/2,2,5/2) | (5/2,3,7/2) | (2,5/2,3)     | (3/2,2,5/2) | (3/2,2,5/2) | 0,176   |
| C2 |         | (1,1,1)     | (1/2,1,3/2)   | (1,1,1)     | (5/2,3,7/2) | (5/2,3,7/2)   | (3/2,2,5/2) | (3/2,2,5/2) | 0,181   |
| C3 |         |             | (1,1,1)       | (5/2,3,7/2) | (5/2,3,7/2) | (2/5,1/2,2/3) | (5/2,3,7/2) | (3/2,2,5/2) | 0,192   |
| C4 |         |             |               | (1,1,1)     | (1/2,1,3/2) | (1/2,1,3/2)   | (3/2,2,5/2) | (3/2,2,5/2) | 0,109   |
| C5 |         |             |               |             | (1,1,1)     | (3/2,2,5/2)   | (3/2,2,5/2) | (3/2,2,5/2) | 0,100   |
| C6 |         |             |               |             |             | (1,1,1)       | (1/2,1,3/2) | (1/2,1,3/2) | 0,091   |
| C7 |         |             |               |             |             |               | (1,1,1)     | (1/2,1,3/2) | 0,073   |
| C8 |         |             |               |             |             |               |             | (1,1,1)     | 0,078   |

The logistic experts prepared PF-AHP decision matrix with respect to Ilbahar's scale [19]. This table is required to employ PF-AHP steps. Pairwise comparisons between the criteria can be seen at the decision Matrix in Table 3, which is generated using the Ilbahar's scale of PF AHP.

The PF-AHP results, which were gained by applying PF-AHP steps described in Section 2, are presented in Table 4. The most important criterion is revealed to be reliability (C3) with respect to PF-AHP results. The sequence of most influential logistic factors to PF-AHP is presented in Table 4 as reliability (C3), speed (C2), cost (C1), customer satisfaction (C4), technological innovations and logistic 4.0 (C8), distribution channel (C5), company image (C6) and environmentally friendliness (C7).

AHP and PF-AHP. Table 5 illustrates the comparative results of three applied methods; e.g. AHP, F-AHP and PF-AHP. The first three criteria are the same in all methods: cost, speed, and reliability, though the orders of first and third criteria in AHP (cost, speed and reliability) are different from F-AHP and PF-AHP (reliability, speed and cost).

The sequence of most influential logistic factors to AHP is cost (C1), speed (C2), reliability (C3), customer satisfaction (C4), company image (C6), distribution channel (C5), technological innovations and logistic 4.0 (C8) and environmentally friendliness (C7) in Table 5. The sequence of most influential logistic factors to F-AHP is reliability (C3), speed (C2), cost (C1), customer satisfaction (C4), distribution channel (C5), company

**Table 3.** Decision Matrix for PF-AHP

|    | C1                           | C2                          | C3                            | C4                          |
|----|------------------------------|-----------------------------|-------------------------------|-----------------------------|
| C1 | (0.196,0.1965),(0.196,0.196) | (0.45,0.55),(0.45,0.55)     | (0.20, 0.35),(0.65,0.80)      | (0.65,0.80),(0.20,0.35)     |
| C2 | (0.45,0.55),(0.45,0.55)      | (0.196,0.196),(0.196,0.196) | (0.45,0.55),(0.45,0.55)       | (0.55,0.65),(0.35,0.45)     |
| C3 | (0.65,0.80),(0.20,0.35)      | (0.45,0.55),(0.45,0.55)     | (0.196,0.1965),(0.1965,0.196) | (0.9,1),(0,0)               |
| C4 | (0.20,0.35),(0.65,0.80)      | (0.45,0.55),(0.45,0.55)     | (0,0),(0,9,1)                 | (0.196,0.196),(0.196,0.196) |
| C5 | (0,0),(0,9,1)                | (0,0),(0,9,1)               | (0,0),(0,9,1)                 | (0.45,0.55),(0.45,0.55)     |
| C6 | (0.10,0.20),(0,8,0,9)        | (0,0),(0,9,1)               | (0.35,0.45),(0.55,0.65)       | (0.45,0.55),(0.45,0.55)     |
| C7 | (0.20,0.35),(0.65,0.80)      | (0.20,0.35),(0.65,0.80)     | (0,0),(0,9,1)                 | (0.20,0.35),(0.65,0.80)     |
| C8 | (0.20,0.35),(0.65,0.80)      | (0.20,0.35),(0.65,0.80)     | (0.35,0.45),(0.55,0.65)       | (0.20,0.35),(0.65,0.80)     |
|    | C5                           | C6                          | C7                            | C8                          |
| C1 | (0,9,1),(0,0)                | (0,8,0,9),(0,10,0,20)       | (0.65,0.80),(0.20,0.35)       | (0.65,0.80),(0.20,0.35)     |
| C2 | (0,9,1),(0,0)                | (0,9,1),(0,0)               | (0.65,0.80),(0.20,0.35)       | (0.65,0.80),(0.20,0.35)     |
| C3 | (0,9,1),(0,0)                | (0,55,0,65),(0,35,0,45)     | (0,9,1),(0,0)                 | (0,55,0,65),(0,35,0,45)     |
| C4 | (0,45,0,55),(0,45,0,55)      | (0,45,0,55),(0,45,0,55)     | (0,65,0,80),(0,20,0,35)       | (0,65,0,80),(0,20,0,35)     |
| C5 | (0,196,0,196),(0,196,0,196)  | (0,65,0,80),(0,20,0,35)     | (0,65,0,80),(0,20,0,35)       | (0,20,0,35),(0,65,0,80)     |
| C6 | (0,20,0,35),(0,65,0,80)      | (0,196,0,196),(0,196,0,196) | (0,45,0,55),(0,45,0,55)       | (0,45,0,55),(0,45,0,55)     |
| C7 | (0,20,0,35),(0,65,0,80)      | (0,45,0,55),(0,45,0,55)     | (0,196,0,196),(0,196,0,196)   | (0,20,0,35),(0,65,0,80)     |
| C8 | (0,65,0,80),(0,20,0,35)      | (0,45,0,55),(0,45,0,55)     | (0,65,0,80),(0,20,0,35)       | (0,196,0,196),(0,196,0,196) |

Results of three applied methods; including AHP, F-AHP and PF-AHP, are investigated. The logistic factors (e.g. C1-C8) are compared with respect to results of AHP, F-

image (C6), technological innovation and logistic 4.0 (C8) and environmentally friendliness (C7) in Table 5.

**Table 4.** Results of PF-AHP

|    | C1    | C2    | C3    | C4     | C5     | C6     | C7     | C8    | Weights |
|----|-------|-------|-------|--------|--------|--------|--------|-------|---------|
| C1 | 1,000 | 0,848 | 0,161 | 3,766  | 19,448 | 9,512  | 3,766  | 3,766 | 0,213   |
| C2 | 0,848 | 1,000 | 0,848 | 1,688  | 19,448 | 19,447 | 3,766  | 3,766 | 0,257   |
| C3 | 3,766 | 0,848 | 1,000 | 19,448 | 19,448 | 1,408  | 19,448 | 1,688 | 0,339   |
| C4 | 0,073 | 0,424 | 0,032 | 1,000  | 0,848  | 0,848  | 3,766  | 3,766 | 0,054   |
| C5 | 0,032 | 0,032 | 0,032 | 0,848  | 1,000  | 3,766  | 3,766  | 0,161 | 0,049   |
| C6 | 0,068 | 0,032 | 0,424 | 0,848  | 0,161  | 1,000  | 0,848  | 0,848 | 0,021   |
| C7 | 0,161 | 0,161 | 0,308 | 0,161  | 0,161  | 0,848  | 1,000  | 0,161 | 0,015   |
| C8 | 0,161 | 0,161 | 0,424 | 0,161  | 3,766  | 0,848  | 3,766  | 1,000 | 0,052   |

**Table 5.** Comparative Analysis of different linguistic scales

| Weights        | AHP          | F-AHP        | PF-AHP       | Order | AHP | F-AHP | PF-AHP |
|----------------|--------------|--------------|--------------|-------|-----|-------|--------|
| W <sub>1</sub> | <b>0,282</b> | <b>0,176</b> | <b>0,213</b> | 1     | 1   | 3     | 3      |
| W <sub>2</sub> | <b>0,219</b> | <b>0,181</b> | <b>0,257</b> | 2     | 2   | 2     | 2      |
| W <sub>3</sub> | <b>0,183</b> | <b>0,192</b> | <b>0,339</b> | 3     | 3   | 1     | 1      |
| W <sub>4</sub> | 0,090        | 0,109        | 0,054        | 4     | 4   | 4     | 4      |
| W <sub>5</sub> | 0,063        | 0,100        | 0,049        | 5     | 6   | 5     | 6      |
| W <sub>6</sub> | 0,074        | 0,091        | 0,021        | 6     | 5   | 6     | 7      |
| W <sub>7</sub> | 0,039        | 0,073        | 0,015        | 7     | 8   | 8     | 8      |
| W <sub>8</sub> | 0,050        | 0,078        | 0,052        | 8     | 7   | 7     | 5      |

The sequence of most influential logistic factors to PF-AHP is reliability (C3), speed (C2), cost (C1), customer satisfaction (C4), technological innovation and logistic 4.0 (C8), distribution channel (C5), company image (C6) and environmentally friendliness (C7) in Table 5..

The top 10 logistic firms (A1-A10) in Turkey are scored, compared and ranked with respect to most influential logistic factors and PF-AHP weights. We employ the PF-AHP weights to rank the logistic firms, because PF-AHP captures the condition for degrees of membership and non-membership greater than 1.

Table 6 illustrates the comparison of logistic firms. We didn't mention the name of logistic firms that are compared due to commercial reasons. Considering most influential logistic factors, rank of logistic firms are (e.g. A6, A7, A9, A4, A10, A2, A1, A8, A5 and A3) different than their economic magnitudes (A1, A2, A3, A4, A5, A6, A7, A8, A9, A10).

**4 CONCLUSION AND FUTURE REMARKS**

Logistic activities have focused on improving services and reducing costs. Research results corroborate this since most significant three criteria are revealed as cost; speed and reliability are in line with this objective in all methods, which are AHP, F-AHP, PF-AHP. We think that the differences with in the AHP, F-AHP and PF-AHP results may stem from expressing evaluation in exact values, linguistic terms or in some cases it may be

related to fulfilling the condition for degrees of membership and non-membership.

Our suggestions for future work is evaluating and comparing the same; e.g. top 10 logistic firms in Turkey with respect to each criterion with a F-MCDM approach based on Pythagorean fuzzy sets. After that F-MCDM evaluation results can be compared with the scoring results gathered in this study.

**NOMENCLATURE**

**AHP:** Analytic Hierarchy Process

**F-AHP:** Fuzzy Analytic Hierarchy Process

**FMEA:** Failure Mode Effect Analysis

**MCDM:** Multi Criteria Decision Making

**MOORA:** Multi-Objective Optimization on the basis of Ratio Analysis

**PF:** Pythagorean Fuzzy

**PFS:** Pythagorean Fuzzy Sets

**PFN:** Pythagorean Fuzzy Numbers

**PF-AHP:** Pythagorean Fuzzy Analytic Hierarchy Process

**PROMETHEE:** The Preference Ranking Organization Method for Enrichment Evaluation

**TOPSIS:** Technique for Order Preference by Similarity to Ideal Solution

**Table 6.** Comparative Analysis of different logistic firms

| Criteria     | Weights  | A1          | A2          | A3          | A4          | A5          | A6          | A7          | A8          | A9          | A10         |
|--------------|----------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| <b>C1</b>    | 0.213    | 80          | 60          | 75          | 85          | 65          | 70          | 85          | 75          | 95          | 90          |
| <b>C2</b>    | 0.257    | 75          | 90          | 85          | 65          | 60          | 75          | 80          | 50          | 60          | 70          |
| <b>C3</b>    | 0.339    | 65          | 65          | 40          | 75          | 70          | 90          | 65          | 75          | 70          | 65          |
| <b>C4</b>    | 0.054    | 50          | 45          | 50          | 85          | 80          | 75          | 70          | 65          | 60          | 50          |
| <b>C5</b>    | 0.049    | 95          | 90          | 70          | 75          | 85          | 85          | 90          | 95          | 95          | 85          |
| <b>C6</b>    | 0.021    | 50          | 55          | 60          | 55          | 45          | 60          | 50          | 70          | 50          | 60          |
| <b>C7</b>    | 0.015    | 20          | 45          | 45          | 60          | 50          | 60          | 85          | 75          | 60          | 55          |
| <b>C8</b>    | 0.052    | 30          | 50          | 40          | 30          | 60          | 50          | 45          | 55          | 65          | 50          |
| <b>Total</b> | <b>1</b> | <b>68.6</b> | <b>69.2</b> | <b>61.5</b> | <b>72.1</b> | <b>66.2</b> | <b>77.6</b> | <b>73.5</b> | <b>67.8</b> | <b>72.6</b> | <b>70.7</b> |

**RBV:** Resource-Based View

**F-VIKOR:** Fuzzy VlseKriterijumska Optimizacija I Kompromisno Resenje,

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