Location selection for a textile manufacturing facility with GIS based on hybrid MCDM approach

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ABSTRACT – REZUMAT

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The establishment of a textile manufacturing facility in any city of a country is a very significant decision since it will have a significant positive effect on the economy of both the city and the country and reduce unemployment in the city. Even though it is a very important decision to establish a textile manufacturing facility, there are very few studies on the location selection of the textile manufacturing facility. This study aims to propose a new integrated MCDM model including FUCOM and PIV-F with GIS to fill this research gap. The criteria used in this study are as follows; Proximity to Airport (PA), Proximity to Highway (PH), Proximity to Shopping Centre (PSC), Proximity to Railway (PR), Proximity to Retailer Centre (PRC), Proximity to Supplier Centre (PSCT), Slope of Land (SL) and Distance to Population Density (DPD). FUCOM was used to obtain criteria weights. PR criterion was designated as the most important criterion with respect to the results of FUCOM. PIV-F method was used to rank suitable areas for a textile manufacturing facility in Sivas province of Turkey. According to the results of PIV-F, Area-4 was determined as the most suitable area for the establishment of a textile manufacturing facility in Sivas province. This study aims to make two contributions to the literature. First, the fuzzy extension of the PIV method is newly developed. Second, a new integrated MCDM-GIS model is used to select the location for the textile manufacturing facility.

Keywords: *MCDM, location selection, GIS, PIV-F, FUCOM*

Selecția locației pentru o companie textilă cu GIS bazată pe abordarea modelului hibrid MCDM

Înființarea unei companii textile în orice oraș al unei țări este o decizie foarte importantă, deoarece va avea un efect pozitiv semnificativ atât asupra economiei orașului, cât și a țării și va reduce șomajul. Chiar dacă este o decizie foarte importantă de a înființa o companie textilă, există foarte puține studii privind selectarea locației. Acest studiu are ca obiectiv propunerea unui nou model integrat MCDM, inclusiv FUCOM și PIV-F cu GIS pentru a umple acest gol în cercetare. Criteriile utilizate în acest studiu sunt următoarele: apropierea de aeroport (PA), apropierea de autostradă (PH), apropierea de centrul comercial (PSC), apropierea de calea ferată (PR), apropierea de centre de vânzare (PRC), apropierea de centrul de furnizare (PSCT), panta terenului (SL) și distanța față de densitatea populației (DPD). FUCOM a fost utilizat pentru a obține ponderile criteriilor. Criteriul PR a fost desemnat drept cel mai important în ceea ce privește rezultatele FUCOM. Metoda PIV-F a fost utilizată pentru a clasifica zonele adecvate pentru o companie textilă din provincia Sivas din Turcia. Conform rezultatelor PIV-F, Zona-4 a fost determinată drept cea mai potrivită pentru înființarea unei companii textile în provincia Sivas. Acest studiu își propune să aducă două contribuții la cercetarea științifică. În primul rând, extensia fuzzy a metodei PIV este recent dezvoltată. În al doilea rând, se utilizează un nou model integrat MCDM-GIS pentru a selecta locația pentru unitatea de producție a produselor textile.

Cuvinte-cheie: *MCDM, selectarea locației, GIS, PIV-F, FUCOM*

INTRODUCTION

The establishing of a new facility is considered as an important and strategic decision problem since the establishment will have long-term effects on the sustainability, availability, and profitability of the facility. One of the most important of these decision processes is choosing the appropriate location for the facility. Improper location choices in today's competitive globe can trigger irrecoverable results for any sector [1]. A methodological, analytical and planned approach to the selection of suitable areas for the facilities will minimize the possibility of inaccurate location selection to a very low level. Although there are many approaches having these attributes in the literature, multi-criteria decision making (MCDM) methods can be used more effectively in solving this problem since there are multiple alternatives in the location selection problem and these alternatives are evaluated under more than one criteria. MCDM as part of operational research is increasingly being utilized to address a range of problems [2]. Nowadays, different MCDM methods have been used to solve different problems [3–5]. In addition to MCDM methods, the GIS (geographic information systems) can be used to solve the location selection problem as the GIS can capture, store, manipulate, handle and, most significantly, evaluate geographic data [1].

In recent years, many different location selection problems have been solved using MCDM methods and GIS in the literature. For instance, the problem of energy-related facility location [6–10], the problem of logistics and warehouse related location selection [11, 12] and the problem of waste-related location selection [13, 14] were analysed by using GIS and MCDM methods.

The textile sector is so important for the economy of Turkey in terms of employment and exports [15]. In August 2019, the share in Turkey's total exports of textiles and raw materials constituted to 5.5% of its overall exports [16]. Turkey's total textile and raw material exports between January 2019 and August 2019 were approximately $ 6.5 billion [16]. As a result, it can be said that the textile sector is the backbone of the Turkish economy.

The establishment of a textile manufacturing facility in any city of a country is a very significant decision since it will have a significant positive effect on the economy of both the city and the country and reduce unemployment in the city. Although the establishment of a textile manufacturing facility is a very important decision, there are very few studies on the selection of textile manufacturing facility location [1]. This study aims to propose a new integrated MCDM model including FUCOM (Full Consistency Method) and PIV-F (Fuzzy Proximity Indexed Value) with GIS to fill this research gap. This study aims to make two contributions to the literature. First, the fuzzy extension of the PIV method is newly developed. Second, a new integrated MCDM-GIS model is used to select the location for the textile manufacturing facility.

METHODOLOGY

FUCOM

FUCOM method developed by Pamučar et al. [17], is used to determine criteria weights as the developers of this method claimed that this method is better than Best Worst Method and Analytic Hierarchy Process. In recent years, successful applications of FUCOM method have been performed [18–22]. This method is summarized as described in Pamučar et al. [17], Nunić [18], Zavadskas et al. [19].

Step 1: Criteria are ranked with respect to their significance level.

Step 2: Ranked criteria are compared to obtain the priorities ($\vartheta_{C_{j(k)}}$) of them and the comparative priority ($\omega_{k/k+1}$) of them is identified.

$$\varpi = (\omega_{1/2}, \omega_{2/3}, \ldots, \omega_{k/k+1}) \tag{1}$$

In equation 1, k is the rank of the criteria.

Step 3: In the final step, criteria weights are calculated; however, weights should fulfil the following 2 conditions.

- The comparative priority is equal to the ratio of weights of criteria. Equation 2 indicates this condition.

$$\omega_{k/k+1} = \frac{w_k}{w_{k+1}} \tag{2}$$

- Criteria weights should fulfil the condition of mathematical transitivity, i.e. $\omega_{k/k+1} \cdot \omega_{k+1/k+2} = \omega_{k/k+2}$.

As $\omega_{k/k+1} = \frac{w_k}{w_{k+1}}$ and $\omega_{k+1/k+2} = \frac{w_{k+1}}{w_{k+2}}$, $\frac{w_k}{w_{k+1}} \cdot \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ is determined. Equation 3 indicates this formula:

$$\frac{w_k}{w_{k+2}} = \omega_{k/k+1} \cdot \omega_{k+1/k+2} \tag{3}$$

The final model is formed to obtain final weights of criteria. Equation 4 presents the final model:

$$\begin{aligned} & Min\ \chi \\ & s.t. \\ & \left| \frac{w_{j(k)}}{w_{j(k+1)}} - \omega_{k/k+1} \right| \leq \chi,\ \forall j \\ & \left| \frac{w_{j(k)}}{w_{j(k+2)}} - \omega_{k/k+1} \right| \cdot \omega_{k+1/k+2} \leq \chi,\ \forall j \\ & \sum_{j=1}^{n} w_j = 1,\ \forall j \\ & w_j \geq 0,\ \forall j \end{aligned} \tag{4}$$

In equation 4, χ indicates a deviation from full consistency and this value should be between 0 and 0.025. These weights will be transferred into PIV-F method.

PIV-F

PIV method (developed by Mufazzal and Muzakkir [23] to minimize rank reversal problem) is used to rank alternatives. Since the PIV method is newly developed, there are very few studies on the application of the PIV method [24, 25]. In this study, the aim of developing PIV-F method is to handle uncertain values and minimize the rank reversal problem. This method consists of 6 steps.

Step 1: A fuzzy decision matrix ($\tilde{S}$) is formed. When forming fuzzy decision matrix, experts use linguistic values indicated in table 1. These linguistic values are converted into fuzzy values by aiding of table 1.

$$\tilde{S} = [\tilde{s}_{ij}]_{m \times n} \tag{5}$$

Table 1

LINGUISTIC AND FUZZY VALUES	
Linguistic values	**Fuzzy values**
Very Low	(0, 1, 3)
Low	(1, 3, 5)
Fair	(3, 5, 7)
High	(5, 7, 9)
Very High	(7, 9, 10)

Step 2: This matrix is normalized as

$$\tilde{t}_{ij} = (t_{ij}^l, t_{ij}^m, t_{ij}^u) = \frac{\tilde{s}_{ij}}{\sqrt{\sum_{i=1}^{m} \tilde{s}_{ij}^2}} = \left(\frac{s_{ij}^l}{\sqrt{\sum_{i=1}^{m} \left[(s_{ij}^l)^2 + (s_{ij}^m)^2 + (s_{ij}^u)^2 \right]}}, \frac{s_{ij}^m}{\sqrt{\sum_{i=1}^{m} \left[(s_{ij}^l)^2 + (s_{ij}^m)^2 + (s_{ij}^u)^2 \right]}}, \frac{s_{ij}^u}{\sqrt{\sum_{i=1}^{m} \left[(s_{ij}^l)^2 + (s_{ij}^m)^2 + (s_{ij}^u)^2 \right]}} \right) \tag{6}$$

In equation 6, $\tilde{t}_{ij} = (t_{ij}^l, t_{ij}^m, t_{ij}^u)$ is the fuzzy normalized value of $\tilde{s}_{ij}$ and a member of fuzzy normalized decision matrix (T).

Step 3: Fuzzy normalized values are multiplied by criteria weights.

$$\tilde{k}_{ij} = \tilde{t}_{ij} \times w_j \tag{7}$$

Step 4: Fuzzy weighted proximity index ($\tilde{v}_{ij}$) is computed as. Equation 8 and 9 are used for beneficial and cost criteria respectively.

$$\begin{aligned}\tilde{v}_{ij} &= (v_{ij}^l, v_{ij}^m, v_{ij}^u) = \max(\tilde{k}_{ij}) - \tilde{k}_{ij} = \\ &= \left(\max(k_{ij}^u) - k_{ij}^u, \max(k_{ij}^u) - k_{ij}^m, \max(k_{ij}^u) - k_{ij}^l\right)\end{aligned} \tag{8}$$

$$\begin{aligned}\tilde{v}_{ij} &= (v_{ij}^l, v_{ij}^m, v_{ij}^u) = \tilde{k}_{ij} - \min(\tilde{k}_{ij}) = \\ &= \left(k_{ij}^l - \min(k_{ij}^l), k_{ij}^m - \min(k_{ij}^l), k_{ij}^u - \min(k_{ij}^l)\right)\end{aligned} \tag{9}$$

Step 5: Fuzzy overall proximity index ($\tilde{d}_i$) is computed as

$$\tilde{d}_i = \sum_{j=1}^{n} \tilde{v}_{ij} = \left(\sum_{j=1}^{n} v_{ij}^l, \sum_{j=1}^{n} v_{ij}^m, \sum_{j=1}^{n} v_{ij}^u\right) \tag{10}$$

Step 6: Fuzzy overall proximity index $(\tilde{d}_i = (d_i^l, d_i^m, d_i^u))$ for each alternative is converted into crisp overall proximity index (d_i).

$$d_i = \frac{d_i^l + d_i^m + d_i^u}{3} \tag{11}$$

The alternative with the smallest crisp overall proximity index is determined as the best alternative.

DATA ACQUISITION AND APPLICATION

In this study, suitable areas for the establishment of the textile manufacturing facility will be determined in Sivas province. These suitable areas will be ranked from the most appropriate area to the most inappropriate area. All data used in the study were taken from the expert team consisting of managers working in the textile sector and academicians studying on the problem of location selection. Eight criteria were determined for use in the assessment in this study. These criteria are Proximity to Airport (PA), Proximity to Highway (PH), Proximity to Shopping Centre (PSC), Proximity to Railway (PR), Proximity to Retailer Centre (PRC), Proximity to Supplier Centre (PSCT), Slope of Land (SL) and Distance to Population Density (DPD). Expert opinions and literature [1] were used in determining the criteria. Only one criterion (SL) was determined as cost criterion and others were determined as beneficial criteria. The data, data source, data format, and analysis method (in GIS) related to the criteria used in the study are shown in table 2.

The application of FUCOM

Expert team ranked criteria based on the consensus: PR > PH > PSC > PA > PRC > PSCT > SL > DPD. Then experts compared criteria based on the scale [1,9] to obtain the priorities of criteria ($\vartheta_{C_{j(k)}}$). These values are indicated in table 3.

After performing the other steps of FUCOM method (equations 1–4), criteria weights are computed. Criteria weights are presented in table 4.

Table 2

THE CRITERIA USED IN THE STUDY AND THE ANALYSIS APPLIED FOR THESE CRITERIA

Criteria	Data	Data Source	Data Format	Analysis
Proximity to railway (PR)	Railway	Environment and Urban Ministry/Landscaping Plan	Vector-line layer	Euclidean distance
Proximity to highway (PH)	Highway	Environment and Urban Ministry/Landscaping Plan	Vector-line layer	Euclidean distance
Proximity to shopping centre (PSC)	Shopping Centre	Google Earth Mapping	Vector-point layer	Euclidean distance
Proximity to airport (PA)	Airport	Environment and Urban Ministry/Landscaping Plan	Vector-polygon layer	Euclidean distance
Proximity to retailer centre (PRC)	Industry	Environment and Urban Ministry/Landscaping Plan	Vector-polygon layer	Euclidean distance
Proximity to supplier centre (PSCT)	Supplier Centre	Google Earth Mapping	Vector-point layer	Euclidean distance
Slope of land (SL)	Slope	U.S. Geological Survey/Digital Elevation Model	Raster (Elevation layer)	Slope
Distance to population density (DPD)	Districts	Turkish Statistical Institution	Vector-point layer	Point density

Table 3

PRIORITIES OF CRITERIA

Criteria	PR	PH	PSC	PA	PRC	PSCT	SL	DPD
$\vartheta_{C_{j(k)}}$	1	1.7	1.9	2.3	2.7	3.1	3.2	3.4

Table 4

CRITERIA WEIGHTS								
Criteria	**PR**	**PH**	**PSC**	**PA**	**PRC**	**PSCT**	**SL**	**DPD**
w_j	0.260	0.153	0.137	0.113	0.096	0.083	0.081	0.071

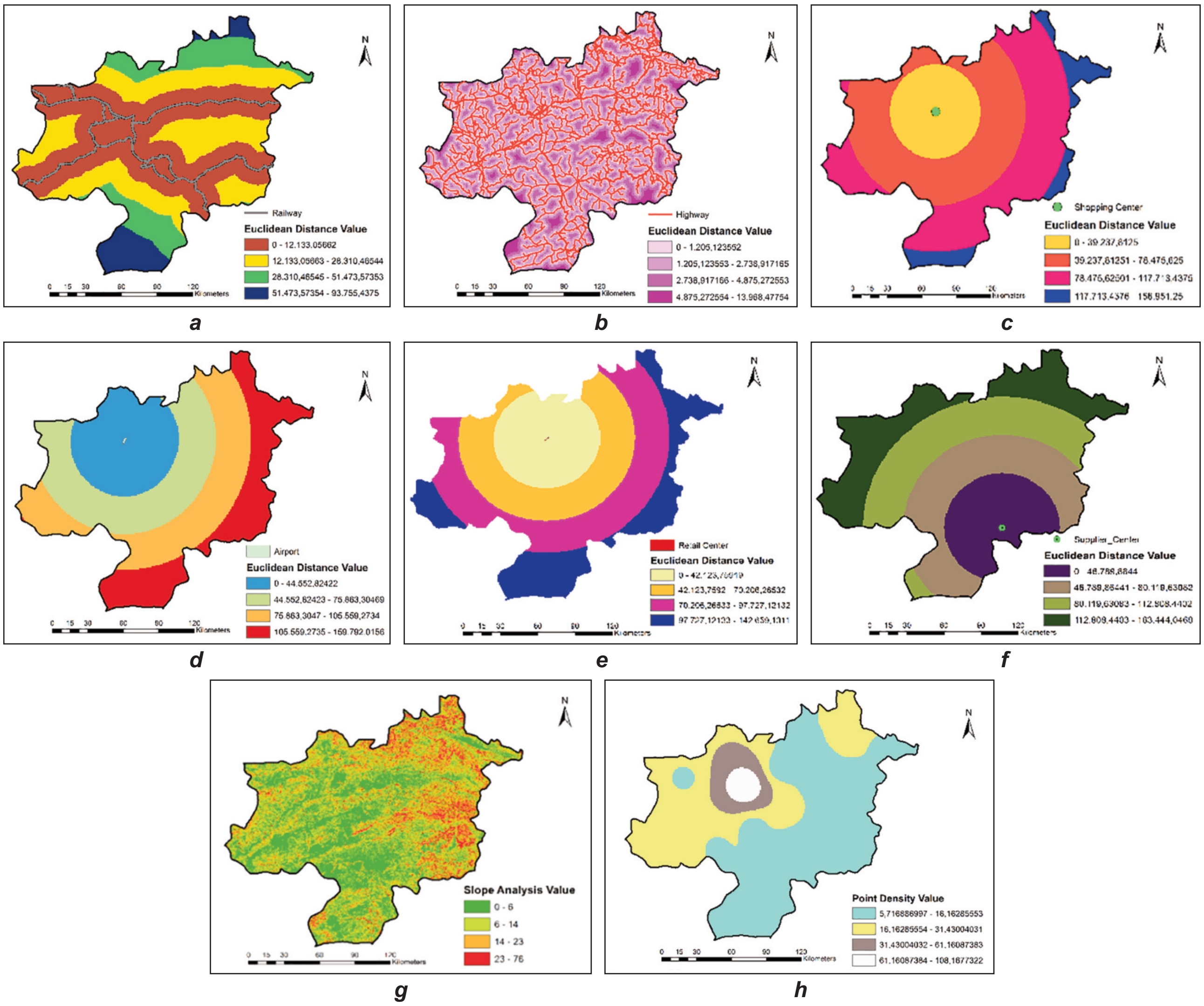

Fig. 1. Criteria maps created according to analysis methods applied in the study: *a* – proximity to railway; *b* – proximity to highway; *c* – proximity to shopping centre; *d* – proximity to airport; *e* – proximity to retail centre; *f* – proximity to supplier centre; *g* – slope of land; *h* – proximity to population density

PR criterion was designated as the most important criterion with respect to the results of FUCOM. According to the results of FUCOM, the deviation from full consistency is 0.021 and this indicates that results are consistent. After FUCOM method, the raster data are obtained with respect to Euclidean Distance Analysis, Slope Analysis and Point Density Analysis that were indicated in table 2. Maps are formed with respect to these data. Figure 1 indicates these maps.

These raster data are reclassified by using table 5. Table 5 presents a number system 1 to 4 (new values (scores)) to reclassify raster data.

With the aid of reclassified raster data and criteria weights (obtained in FUCOM), the suitable areas for the textile manufacturing facility are determined. These areas are indicated in figure 2.

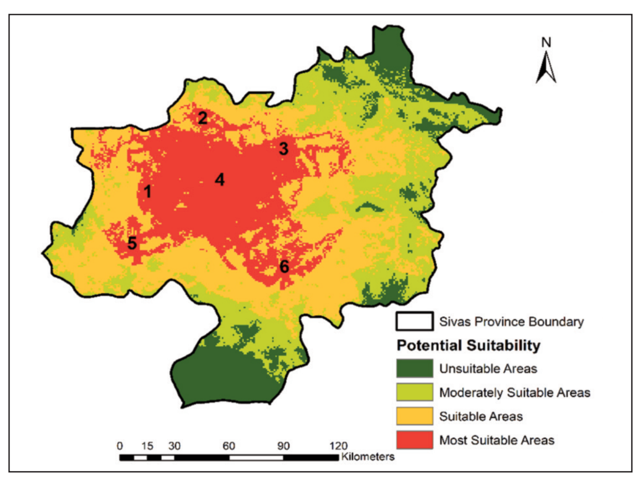

Fig. 2. Suitable areas for textile manufacturing facility

Table 5

THE SCORES AND SUB-CRITERION VALUES OBTAINED ACCORDING TO THE ANALYSIS METHODS APPLIED FOR THE CRITERIA USED IN THE STUDY		
Criteria	**Old values**	**New values (Scores)**
Proximity to railway (m)	0–12.133,056	4
	12.133,056–28.310,465	3
	28.310,465–51.473,573	2
	51.473,573–93.755,43	1
Proximity to highway (m)	0–1.205,123	4
	1.205,123–2.738,917	3
	2.738,917–4.875,272	2
	4.875,272–13.968,47	1
Proximity to shopping centre (m)	0–39.237,8125	4
	39.237,8125–78.475,625	3
	78.475,625–117.713,4375	2
	117.713,4375–156.951,25	1
Proximity to airport (m)	0–44.552,824	4
	44.552,824–75.863,304	3
	75.863,304–105.559,273	2
	105.559,273–159.792,01	1
Proximity to retailer centre (m)	0–42.123,75919	4
	42.123,75919–70.206,26532	3
	70.206,26532–97.727,12132	2
	97.727,12132–142.659,1311	1
Proximity to supplier centre (m)	0–46.789,8644	4
	46.789,8644–80.119,63082	3
	80.119,63082–112.808,4402	2
	112.808,4402–163.444,0469	1
Slope of land (Degree)	0–6	4
	6–14	3
	14–23	2
	23–76	1
Proximity to population density (person/km^2)	5,71–16,16	1
	16,16–31,43	2
	31,43–61,16	3
	61,16–108,16	4

The application of PIV-F

Expert team evaluated suitable areas, which are indicated in figure 2, by using table 1 to obtain fuzzy decision matrix. This matrix is presented in table 6. With the use of equation 6 and 7, normalized and weighted normalized matrices are obtained respectively. By using equation 8 and 9, fuzzy weighted proximity index values are determined. These values are indicated in table 7.

With the aid of equation 10 and 11, fuzzy overall proximity index and crisp overall proximity index are calculated respectively. Table 8 indicates the results of PIV-F including fuzzy and crisp overall proximity indexes and rankings of areas.

According to the results of PIV-F, areas are sorted as follows: Area-4, Area-3, Area-1, Area-5, Area-2, and Area-6. PIV-F method is compared with the other fuzzy MCDM methods (fuzzy ARAS, fuzzy MOORA and fuzzy MABAC) to determine whether the PIV-F method has reached the accurate results. The rankings of areas according to the results of PIV-F and other fuzzy MCDM methods are presented in table 9. Spearman correlation coefficients between PIV-F method and other fuzzy MCDM methods are as follows. PIV-F-fuzzy ARAS, PIV-F-fuzzy MOORA, and PIV-F-fuzzy MABAC correlation coefficients are 0.943, 1.000 and 0.943, respectively. The correlations between the methods have been observed to be very high and therefore it can be concluded that the PIV-F method achieves accurate results.

CONCLUSIONS

Establishing a textile manufacturing facility in any city of a country is a very important judgment as it will have an important beneficial impact on both the city and the country's economy and will decrease unemployment in the city. Even though it is a very important decision to establish a textile manufacturing facility, there are very few studies on the location selection of the textile manufacturing facility [1]. This study aims to propose a new integrated MCDM model including FUCOM and PIV-F with GIS to fill this research gap. The criteria used in this study are as follows; PA, PH, PSC, PR, PRC, PSCT, SL and DPD. FUCOM was used to obtain criteria weights. PR criterion was designated as the most important criterion with respect to the results of FUCOM. PIV-F

Table 6

FUZZY DECISION MATRIX								
Criteria / Areas	**PA**	**PH**	**PSC**	**PR**	**PRC**	**PSCT**	**SL**	**DPD**
Area-1	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)
Area-2	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)	(5, 7, 9)	(0, 1, 3)	(5, 7, 9)	(5, 7, 9)
Area-3	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(7, 9, 10)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)
Area-4	(7, 9, 10)	(7, 9, 10)	(7, 9, 10)	(7, 9, 10)	(7, 9, 10)	(3, 5, 7)	(3, 5, 7)	(7, 9, 10)
Area-5	(3, 5, 7)	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)	(1, 3, 5)	(1, 3, 5)	(1, 3, 5)	(3, 5, 7)
Area-6	(1, 3, 5)	(5, 7, 9)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(7, 9, 10)	(3, 5, 7)	(1, 3, 5)

Table 7

FUZZY WEIGHTED PROXIMITY INDEX VALUES				
Areas \ Criteria	PA	PH	PSC	PR
Area-1	(0.004, 0.012, 0.020)	(0.005, 0.014, 0.024)	(0.005, 0.014, 0.024)	(0.032, 0.053, 0.074)
Area-2	(0.004, 0.012, 0.020)	(0.005, 0.014, 0.024)	(0.005, 0.014, 0.024)	(0.053, 0.074, 0.095)
Area-3	(0.004, 0.012, 0.020)	(0.005, 0.014, 0.024)	(0.005, 0.014, 0.024)	(0.032, 0.053, 0.074)
Area-4	(0, 0.004, 0.012)	(0, 0.005, 0.014)	(0, 0.005, 0.014)	(0, 0.010, 0.032)
Area-5	(0.012, 0.020, 0.028)	(0.005, 0.014, 0.024)	(0.014, 0.024, 0.034)	(0.032, 0.053, 0.074)
Area-6	(0.020, 0.028, 0.036)	(0.005, 0.014, 0.024)	(0.024, 0.034, 0.043)	(0.032, 0.053, 0.074)
Areas \ Criteria	PRC	PSCT	SL	DPD
Area-1	(0.011, 0.018, 0.025)	(0.020, 0.028, 0.036)	(0.007, 0.014, 0.021)	(0.003, 0.008, 0.014)
Area-2	(0.004, 0.011, 0.018)	(0.028, 0.036, 0.040)	(0.014, 0.021, 0.028)	(0.003, 0.008, 0.014)
Area-3	(0, 0.004, 0.011)	(0.020, 0.028, 0.036)	(0.007, 0.014, 0.021)	(0.003, 0.008, 0.014)
Area-4	(0, 0.004, 0.011)	(0.012, 0.020, 0.028)	(0.007, 0.014, 0.021)	(0, 0.003, 0.008)
Area-5	(0.018, 0.025, 0.032)	(0.020, 0.028, 0.036)	(0, 0.007, 0.014)	(0.008, 0.014, 0.019)
Area-6	(0.018, 0.025, 0.032)	(0, 0.004, 0.012)	(0.007, 0.014, 0.021)	(0.014, 0.019, 0.024)

Table 8

THE RESULTS OF PIV-F			
Areas \ Results	$\tilde{d}_i$	d_i	Rankings
Area-1	(0.087, 0.161, 0.238)	0.1620	3
Area-2	(0.116, 0.190, 0.263)	0.1897	5
Area-3	(0.076, 0.147, 0.224)	0.1490	2
Area-4	(0.019, 0.065, 0.140)	0.0747	1
Area-5	(0.109, 0.185, 0.261)	0.1850	4
Area-6	(0.120, 0.191, 0.266)	0.1923	6

Table 9

THE RESULTS OF FUZZY MCDM METHODS				
Areas \ Results	PIV-F	Fuzzy ARAS	Fuzzy MOORA	Fuzzy MABAC
Area-1	3	3	3	3
Area-2	5	6	5	4
Area-3	2	2	2	2
Area-4	1	1	1	1
Area-5	4	4	4	5
Area-6	6	5	6	6

method was used to rank suitable areas for a textile manufacturing facility in Sivas province. According to the results of PIV-F, Area-4 was determined as the most suitable area for the establishment of a textile manufacturing facility in Sivas province. PIV-F method was compared with the other fuzzy MCDM methods (fuzzy ARAS, fuzzy MOORA and fuzzy MABAC) to determine whether the PIV-F method has reached the accurate results. The correlations between the methods have been observed to be very high and therefore it can be concluded that the PIV-F method achieves accurate results. This study aimed to make two contributions to the literature. First, the fuzzy extension of the PIV method was newly developed. Second, a new integrated MCDM-GIS model was used to select the location for the textile manufacturing facility. Future studies may use new PIV-F method to solve different MCDM methods.

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