International Journal of Hospital Research 2018, 7 (4)
http://ijhr.iums.ac.ir
Research Article

IJHR
Open Access

Evaluation and Selection of Most Preferable Supplementary Blood Centers in The Case of Tehran

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Abstract

Background and Objective: The efficiency of health system services is a critical measure for societies development. During the last fifty years, the world has witnessed a massive increase in health expenditure, and health-related cost, especially in developing countries, is the main obstacle in the way of advance in health care systems. As a remarkable portion of this cost belongs to blood supply chains, almost any improvement in performance is considered as a critical part of health systems, which contributes to modifying cost-savings and responsiveness policies.

Method: In this paper, a novel multi-criteria decision-making technique is conceptually proposed and presented to location supplementary blood centers so as to prevent disruption to a large extent. In this respect, Grey theory and TOPSIS, a distance-based multiple criteria method, are employed to integrate and evaluate the alternative performance for selecting supplementary blood centers. From a research perspective, TOPSIS method is improved to more effectively tackle grey numbers by presenting a degree of likelihood instead of converting grey numbers into crisp numbers functions, that provides the more flexible ranking procedure.

Results: The real data from Tehran blood transfusion center is applied to validate the method and provide insight into its operational execution, obtained results and validity. Overall, this paper found the proposed hybridized methodology to provide relatively consistent results of top-performing alternatives comparing with the more complicated and less intuitively appealing grey-rough set theory approach.

Conclusion: The proposed hybrid methodology is a useful tool for managers, as well as researchers, who seek to evaluate alternative performance in various studies related to multi-criteria decision making. The technique can also be applied in a regular spreadsheet situation, can take into consideration a variety of metrics, both tangible and intangible, and can be devised with a minimal outside effort from decision-makers and be based completely on archival data if necessary.

Keywords: Blood Supply Chain; Supplementary Blood Center; TOPSIS, Grey Theory; Uncertainty.

Background and objective

In recent decades, the fast-growing in world population has naturally led to a considerable increase in casualties, diseases, and pollution rates, which redouble the significance of health care considerations. Among the matters related to the health care system, blood and its subproducts are lifesaving commodities because they can not be replaced by any alternatives, and moreover, each of them has its special usage. In addition, blood-related cost accounts for a central part of total healthcare expenditures. Regarding the report of GDP[1], healthcare systems are responsible for about 70% of the growth in non-interest spending. By 2040, the related costs of healthcare systems are expected to grow by about 54%. As researchers have mainly addressed the blood issues in the supply chain, investigating the blood supply chain (BSC) is of considerable importance. The BSC starts with the blood donors and an end with the patients, but ultimately it is the requirement for blood by the patient that drives the chain, and hence the blood donors play a critical part.

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Therefore, BSC management has great importance in health care systems; and that is why the blood system has drawn the attention of researchers.

In almost all cases, the donation of blood and then its transfusion, as well as deriving by-products, do not make in an isolated situation, and these series of the process are almost inseparable. Hence, it can be noted to have an efficient healthcare system, a forward and meticulous planning to properly manage BSC is necessary. Indeed, blood supplies are the pillar of healthcare systems, which contributes to saving the patients' lives in daily medical treatments. In this regard, volunteer blood donors are considered as the main sources of blood, and as the process of blood donation is free, it may be supposed that the blood provision cost is relatively low, whereas various parameters such as technological advancements, lifestyle factors, and aging of population charge an increasing cost to healthcare systems, and thus, to the BSCs. At any rate, in BSC, the ultimate aim is to provide safe and sufficient amount of blood to patients considering the related costs and complexity of processes.[2]

Considering the plurality of uncertain factors, to prevent blood shortage and the network collapse under disruptions, this paper takes the backup blood center into account as a supplementary facility to the single regional blood center in the concerned blood supply chain network. Deciding about the supplementary facilities, which enable to concurrently help and support blood production process along with contributing to the process of blood collection, needs the concurrent observation of several attributes. Accordingly, in this paper for identifying appropriate alternatives for supplementary blood centers, an efficient decision-making method is proposed, which integrates the TOPSIS method and Grey system.

The main aim of this paper is to propose and apply the above-mentioned method to select supplementary blood facilities. This research makes a major contribution to integrating the TOPSIS technique and interval grey numbers using likelihood multiple criteria decision making (MCDM) method. Under many changes in alternatives features, crisp data is insufficient to estimate vague decision-maker evaluations. In this regard, Grey numbers can incorporate vagueness of decision-makers' opinion and assessment to the proposed problem. Based on grey number principles, we develop a novel likelihood value for alternative ranking, which provides a more flexible ranking process. Thus, the grey hybrid likelihood MCDM model can assist in strengthening the comprehensiveness of the uncertain decision-making process and also, can be successfully tailored to different stochastic MCDM problems.

The rest of the paper is structured as follows. The related research is reviewed in Section 2. Section 3 provides a research methodology (Grey-TOPSIS) and then in Section 4, a real case study devised for this paper. Finally, the conclusion of the paper, as well as a suggested field for future research, are presented in Section 5.

Relate Research

In this section, a review of the literature background is carried out in line with two major features of the current paper, that is blood supply chain and multi-criteria methods. The related reviewed studies are presented in sub-section 2.1 and 2.2, respectively.

Literature review of the blood supply chain network

Blood supply chain benefits rich literature that their reviewing is too time-consuming and almost frustrating. Therefore, recently published papers are herein investigated from 2017 so far.

As an outstanding study in the realm of the BSC, Fahimnia et al. have developed a stochastic bi-objective optimization model along with considering disastrous situations for designing an efficient BSC network. In this model, the first and the second objective seek to minimize the total cost incurred by the supply chain and the blood delivery time, respectively. To solve this model, a mixed solution technique, combining Lagrangian relaxation and ε-constraint methods, has been employed.[3] In another study, Dillon et al.[4] have proposed a two-stage stochastic programming mathematical model for red blood cell inventory management among hospitals to implement coherent policies toward inventory control. In this model, red blood cell was taken a perishable product into consideration which its supply and demand parameters were uncertain. Moreover, ABO-Rh(D) compatibility, as well as the plurality blood groups, were considered in the proposed optimization model.

In a special paper for blood platelet transfusion services, Ensafian et al.[5] have developed an integrated network which considers ABO-Rh(D) matching rules as well as three types of patients in accordance with their need to ABO-Rh(D) compatibility and platelet age. First of all, using a discrete Markov chain process, they predicted the amount of blood supply. Accordingly, they proposed a deterministic mathematical optimization model in the form of mixed-integer programming. Then in the second step, owing to the inherent uncertainty in blood demand, the model expanded into a two-stage stochastic programming one; and at last, they provided a technique for scenario generation and reduction to make the proposed model tractable in terms of obtaining optimal solution in a reasonable time. Cheraghi and Hosseini-Motlagh[6] have proposed a mixed-integer bi-objective robust programming for disaster relief to appropriately manage BSCs. This study provided a three-phase method that in the first phase, a fuzzy-VIKOR approach was devised to find out appropriate potential locations to establish blood facilities as a strategic-level decision. In the second phase, a stochastic-robust optimization method was tailored to the proposed model to tackle both disruption and operational risks. Finally, in the third phase, a solution method was developed to tackle the bi-objective formulation. In this paper, ABO-Rh(D) criteria were assumed in the model, and with respect to the urgency level of injured, the demand for blood was prioritized.

In recent research, from an enhancement perspective, Samani and Hosseini-Motlagh[7] have developed an integrated programming model which considers these complexities: consideration of disruption and operational risks simultaneously, diversity and perishability of blood products, and their related shelf lives. In this study, to cope with disruption risk, a mixed two-phase method was developed in which the first phase combines Fuzzy AHP-GRA method and p-robust formulation, and in the second phase, to cope with operational risk, fuzzy-robust programming was developed. In another study, Hamdan and Diabat[8] have proposed a multi-objective programming formulation to properly manage the RBC supply chain. They have converted the deterministic model to a two-stage one assuming the uncertainty in blood supply and demand parameters. In their model, the first objective function minimizes the total costs of blood network, the second objective function aims to minimize blood delivery time, and the last one seeks to minimize the number of outdated blood product. Eventually, to solve the proposed multi-objective model, the ε-constraint technique was employed to the solution method.

When it comes to the collection phase of the blood supply chain network, Ramezanian and Behboodi[9] have developed a mixed-integer linear programming model in which the objective function was considered to minimize the total cost of the system. The proposed model emphasized social aspects for increasing the motivation to donate blood. Also, they have considered uncertainty in demand and tactical parameters, and then, proposed robust programming to properly tackle these imprecise parameters. Zahiri and Pishvaee[10] have introduced an integrated model to design a blood supply chain network and applied the compatibility of blood groups into the model. They have developed a bi-objective optimization model which the first objective aims to minimize the total cost of blood network, and the second one minimizes the maximum level of unsatisfied demand. The authors have used a fuzzy-robust approach to cope with uncertain parameters. Moreover, they assessed the application of the model by applying a real-world case study of Mazandaran province into the proposed optimization model. In a similar study, Samani et al.[11] have proposed a mixed-integer optimization model for blood supply chain network design in disaster relief settings. In this study, they have focused on the trade-off between the efficiency, effectiveness, and responsiveness evaluated by the total cost of blood supply chain network, the freshness of the blood units, and the level of demand satisfaction, respectively. They have formulated a multi-objective mixed-integer linear model under the stochastic condition in blood demand and supply as well as the perishability of blood products.

Literature review of multi-criteria decision-making problems

Since there are many factors that influence on the decision-making process, the location problem herein, it is important to have an understanding about influential factors on the decision as well as what decision-making method should be used. Recently, a literature review carried out by Ho et al.[12] showed that from the first decade of this millennia, there were a vast number of studies in the peer-reviewed literature that utilized many forms of multi-criteria decision model tools. Thus, in this paper, owing to the plurality of papers in the field multi-criteria decision making, we address some recent study in a related field.

In the realm of multi-criteria decision making, the most prevailing methods that have included mathematical model and multiple criteria tools are data envelopment analysis (DEA), the analytical hierarchy and analytical network process (AHP/ANP respectively), mathematical programming models, genetic algorithms (GA), fuzzy set theory, simple multi-attribute rating technique (SMART), and the combination of them (Ho et al., 2010). However, over time, the researchers developed some novel approaches to multi-criteria decision making such as rough set theory (entropy methods) and TOPSIS.[13,14] As many decision processes made under uncertain condition, considering stochastic methods in multi-criteria decision-making problem is of great importance. In this regard, one of a novel method proposed by researchers is grey systems, that in the following, we address the integration of grey theory and TOPSIS method.

The grey systems theory, firstly proposed by Deng[15,16] is a technique that concentrates on problems involving paucity of information. In Grey systems, white denotes complete information, while black represents unknown information. In this respect, grey refers to partially known along with partially unknown information. That is, a grey number implies a number whose exact value is almost unknown, but an interval (upper and lower bound) within which the value lies is known.[17] The grey theory can be adopted for a variety of decision-making tools such as DEMATEL, AHP, and TOPSIS. Haq and Kannan[18] have formulated a vendor selection problem using Grey Relational Analysis (GRA) and AHP. Kuo et al.[19] have applied GRA to a problem engaged with facility layout and dispatching rules selection. Devising a hybrid of grey-fuzzy number and DEMATEL method, Tseng[20] have developed a real estate agent service quality expectation ranking problem. In another study, in a contractor selection problem, Zavadskas et al.[21] have compared TOPSIS-Grey, and SAW-G approached. In a similar study for construction projects, Zavadskas et al.[22] have compared COPRAS-G and TOPSIS-Grey method in the domain of risk appraisal. In the field of MCDM problems, Torkzad and Beheshtinia[23] developed a novel MCDM method to evaluate the criteria which affect hospitals quality. In this paper, novel and comprehensive criteria are developed for quality of hospitals assessments. Furthermore, a mixed MCDM approach is tailored to get the final rankings of hospitals. In another effort, Sedady and Beheshtinia[24] developed an MCDM approach to select the priority of renewable power plants with considering social, economic, environmental, and political aspects. Furthermore, a novel mixed MCDM approach is proposed for prioritizing the power plants construction. Beheshtinia and Omidi[25] proposed a mixed MCDM approach for evaluating the performance of banks according to the criteria of the balanced scorecard (BSC) and corporate social responsibility (CSR) views. Beheshtinia and Nemati-Abozar[26] developed a new mixed technique to rank the suppliers in the advertising industry. Their technique integrates the Modified Digital Logic (MDL) and TOPSIS method by using fuzzy sets theory. In another study, Beheshtinia and Abhari[27] presented a novel technique to obtain an appropriate technology transfer strategy for roller concrete road pavement by hybridizing Modified Digital Logic (MDL) and TOPSIS methods.

Grey TOPSIS, similar to other multi-criteria decision-making tools, has its pros and cons. The pros include its relative mathematical transparency along with ease-of-use. Additionally, it can also be very effective in integrating a wide variety of attributes such as strategic and operational factors as well as tangible and intangible aspects. Unlike other decision-making tools such as AHP that require significant involvement of decision-makers and experts, historical or secondary data can be applied to grey TOPSIS method with little or even no decision-maker involvement. On the other hand, the disadvantages of this method include the need to identify and develop translational ranges for grey numbers. Another disadvantage is when decision-makers are involved, aggregation of decision-makers' opinions as inputs can carry out through various ways ranging from simple averaging to variations in weighted averages; of course, it may show the flexibility that can be considered as an advantage.[28-31] As in the proposed technique in this paper, we seek to find a suitable location for selecting supplementary blood facilities, three categories of influential factors on the location are taken into account. Along with integrating the grey system with TOPSIS, the degree of likelihood measure is introduced to further validate the proposed approach using real data. In should be noted to the best of our knowledge, a comparing validation TOPSIS method to other multi-criteria decision-making techniques almost did not exist in the related research. Here, we set out to provide the integration of Gery numbers and TOPSIS method.

Method

In this section, the grey system theory (number), on which the valuation approach based, is presented to employ it for intangible measures and metrics. Then, TOPSIS as one of the most popular multi-criteria decision analysis method is reviewed.

Grey numbers

When it comes to discrete data and incomplete information that have uncertainties, grey numbers and systems can be utilized to tackle the uncertainty. Concerning the application of grey numbers, the systems with relatively small data sets with great factor variability are engaged in these matters. Supply chain management, economics, geography, agriculture, medicine, and disaster management are some research area that deals with grey numbers and systems. In this paper, the grey numbering system is integrated with a multi-criteria decision analysis method, that is TOPSIS.

Definition 1: $\otimes z$ is considered as a grey number that denotes an interval value $[\underline{z}, \overline{z}]$, where $\underline{z}$ and $\overline{z}$ are respectively the given lower and upper bounds of $\otimes z$. However, it should be noted that the distribution of information for z is unknown. Then, a grey number can be demonstrated as $\otimes z = [\underline{z}, \overline{z}] = [z' \in z | \underline{z} \leq z' \leq \overline{z}]$.

Definition 2: Suppose $\otimes z = [\underline{z}, \overline{z}]$ and $\otimes w = [\underline{w}, \overline{w}]$ are two grey numbers. For these two interval grey number, mathematical operations are defined as expression 1 to 4:

$$\otimes z + \otimes w = [\underline{z} + \underline{w}, \overline{z} + \overline{w}] \quad (1)$$

$$\otimes z - \otimes w = [\underline{z} - \overline{w}, \overline{z} - \underline{w}] \quad (2)$$

$$\otimes z \times \otimes w = \begin{bmatrix} \min(\underline{zw}, \underline{z}\overline{w}, \overline{z}\underline{w}, \overline{zw}), \\ \max(\underline{zw}, \underline{z}\overline{w}, \overline{z}\underline{w}, \overline{zw}) \end{bmatrix} \quad (3)$$

$$\otimes z \div \otimes w = [\underline{z}, \overline{z}] \times \left[\frac{1}{\underline{w}}, \frac{1}{\overline{w}}\right] \quad (4)$$

Definition 3: Suppose $\otimes z = [\underline{z}, \overline{z}]$ and $\otimes w = [\underline{w}, \overline{w}]$ are two interval grey numbers, considering $l(\otimes z) = \overline{z} - \underline{z}$, $l(\otimes w) = \overline{w} - \underline{w}$. Regarding four previous expressions, the larger degrees for two interval grey numbers is defined as follows:

$$p(\otimes z \geq \otimes w) = \begin{cases} 1 & \underline{z} \geq \overline{w} \\ \dfrac{\overline{z} - \underline{w}}{l(\otimes z) + l(\otimes w)} & \overline{z} > \underline{w} \wedge \underline{z} < \overline{w} \\ 0 & \overline{z} \leq \underline{w} \end{cases} \quad (5)$$

where $p(\otimes z \geq \otimes w) > 50\%$ denotes that the interval grey number z, i.e., $\otimes z$, is larger than interval grey number w, i.e. $\otimes w$. In the following, these relations will be employed to develop the TOPSIS method.

The TOPSIS method

TOPSIS is a multi-criteria decision analysis method that compares a set of alternatives by calculating the shortest geometric distance from the ideal (best) solution as well as the largest geometric distance from the nadir (poorest) solution[30]. The TOPSIS process is carried out as follows:

1) The normalized decision matrix $U = (z_{ij})_{nm}$. In the presented model, some grey scale matrixes are developed (see Tables 3 and 5) to correspond all data types to the same grey number interval of "0−1".
2) For each criterion, the ideal and nadir solutions should be determined:

$$O^+ = \{u_1^+, \dots, u_m^+\} = \{(\max u_{ij} \,|j \in I), (\min u_{ij} \,|j \in J)\}; \quad (6)$$

$$O^- = \{u_1^+, \dots, u_m^+\} = \{(\min u_{ij} \,|j \in I), (\max u_{ij} \,|j \in J)\}; \quad (7)$$

where I implies criteria that improve as they get larger, and J denotes criteria that improve as they get smaller.

1) The n-dimensional Euclidian space distance for each alternative from the positive ideal solution should be calculated as follows:

$$\rho_i^+ = \sqrt{\sum_{j=1}^{m} (u_{ij} - u_j^+)^2}, \quad i = 1,2,\dots,n \quad (8)$$

and for the negative (nadir) ideal solution should be calculated as follows:

$$\rho_i^- = \sqrt{\sum_{j=1}^{m} (u_{ij} - u_j^-)^2}, \quad i = 1,2,\dots,n \quad (9)$$

2) The relative closeness is then calculated for each alternative using

$$K_i = \frac{\rho_i^-}{\rho_i^- + \rho_i^+} \quad (10)$$

3) Ranking alternatives by the descending order, the final preference list is obtained.

In the subsequent section, the integrating process of the grey numbering system and TOPSIS technique is provided in an illustrative case study. Also, Schematic view of research methodology for verification of results is shown in Figure 1.

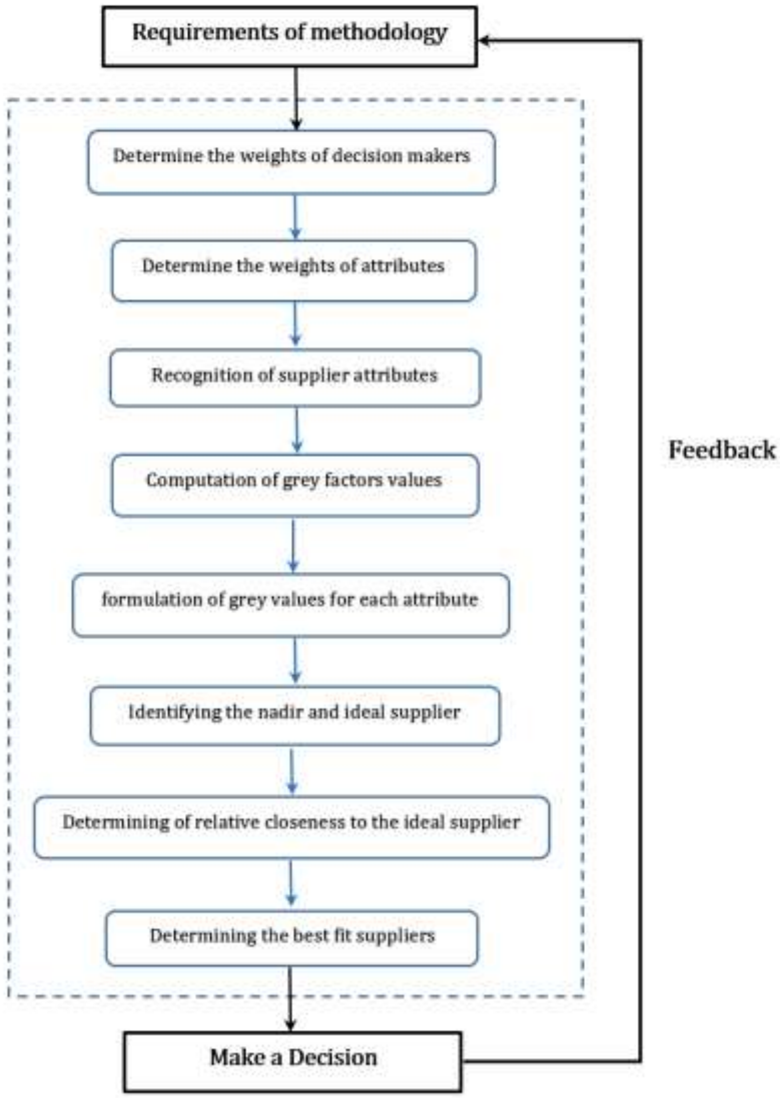

Figure 1. Schematic view of research methodology

Results

A Real Case Study

In this section, a real-world case is meticulously provided to show the application of the proposed methodology as well as the validity solutions. In this regard, a case study of the blood supply chain network in Tehran is investigated to improve the current blood network by more efficiently designed. Additionally, gathering the required data to embed in the methodology, the field experts' knowledge and reliable documents obtained from Iran blood transfusion organization (IBTO), relevant local studies, and the municipality of Tehran are considered three main sources for the presented method. It should be noted that Tehran, as the most populated city in Iran, has a population of 8,693,706. In Tehran, 22 donation zones feed blood supply chain network whose geographic coordinates is demonstrated in Table 1. Furthermore, the geographical dispersion of the 22 municipal districts of Tehran is depicted in Figure 2. Interestingly, as the most critical center of IBTO, Tehran blood supply chain network through its sole regional blood center (RBC) (i.e., Vesal blood center), is responsible for the procuring of nearly one-third of the country's demand for blood.[32-35]

Table 1. The properties of each district of Tehran (Adopted from [7])

District	(Lat, Long)	District	(Lat, Long)
1	(35.80250, 51.45972)	12	(35.68000, 51.42639)
2	(35.75750, 51.36222)	13	(35.70778, 51.51417)
3	(35.75444, 51.44806)	14	(35.67444, 51.47028)
4	(35.74194, 51.49194)	15	(35.63083, 51.47361)
5	(35.74889, 51.30028)	16	(35.63944, 51.40917)
6	(35.73722, 51.40583)	17	(35.65389, 51.36306)
7	(35.72194, 51.44611)	18	(35.65167, 51.29278)
8	(35.72444, 51.49833)	19	(35.62056, 51.36694)
9	(35.68361, 51.31722)	20	(35.59028, 51.44083)
10	(35.68361, 51.36667)	21	(35.69056, 51.25778)
11	(35.67944, 51.39583)	22	(35.74722, 51.20417)

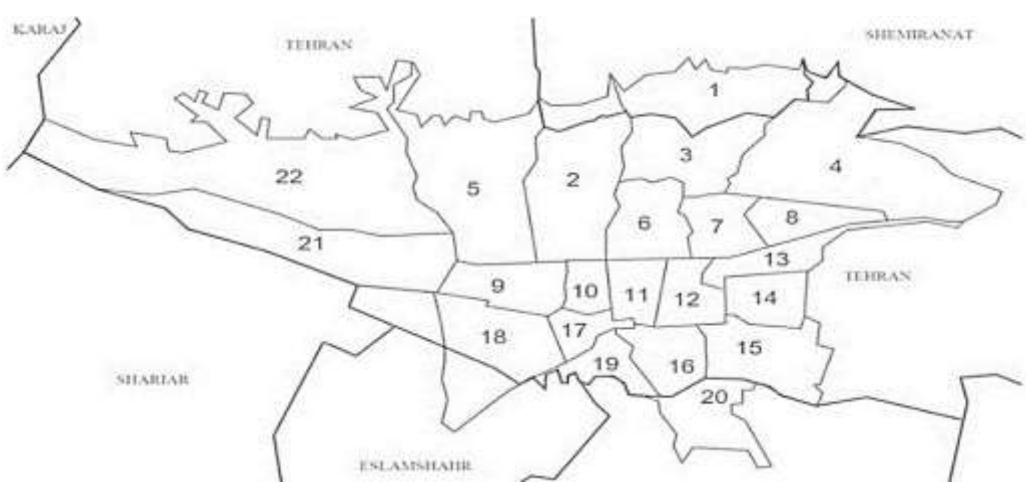

Figure 2. Geographical dispersion of 22 municipal districts of Tehran

Bearing Tehran population dense and its critical role in the provision of blood for the whole country in mind, any interruption or disruption in operating of blood supply chain network may lead to a serious risk to the entire country. Meanwhile, in addition to the current regional blood centers around the country, establishing supplementary blood center to contribute into the blood production process is highly beneficial for the BSC network of Tehran.[36,37]

The geographic coordinates of Tehran blood supply chain network facilities such as respective regional blood centers as well as the current local blood centers along with the hospitals dispersed around the city are presented in Tables 2 and 3.[38-40] Moreover, the location and geographical dispersion of the facilities as well as hospitals are demonstrated in Figure 3.

Table 2. The properties of each local blood center (LBC) (Adopted from [7])

Number	LBC	(Lat, Long)	Number	LBC	(Lat, Long)
1	Vesal	(35.701860, 51.399604)	9	Shahre-Rey	(35.593515, 51.423382)
2	Sadeghieh	(35.722860, 51.334728)	10	Varamin	(35.324263, 51.638855)
3	Chizar	(35.796751, 51.454296)	11	Shahriar	(35.658537, 51.053624)
4	Shohadaye Tajrish	(35.711814, 51.431447)	12	Afsarieh	(35.646060, 51.490722)
5	Shahid Rajae	(35.671761, 51.408321)	13	Piroozi	(35.692609, 51.480927)
6	Milad	(35.745969, 51.381140)	14	Khorasan	(35.665621, 51.445784)
7	Azadi	(35.699724, 51.338061)	15	Robat-Karim	(35.479250, 51.082463)
8	Emam Khomeini	(35.684167, 51.420301)	16	Shahre-Ghods	(35.715176, 51.121660)

Table 3. The properties of each hospital (Adopted from [7])

Number	Hospital	(Lat, Long)	Number	Hospital	(Lat, Long)
1	Mahak	(35.811567, 51.504556)	8	Azadi	(35. 696808, 51. 356958)
2	Milad	(35.746121, 51.381280)	9	Madaen	(35. 672930, 51. 393630)
3	Valieasr	(35.756199, 51.395105)	10	Seyyed-Al-Shohada	(35. 677736, 51. 416359)
4	Labafinejad	(35.767526, 51.462657)	11	Mahdiyeh	(35. 652341, 51. 435430)
5	Sarem	(35.714756, 51.310806)	12	Ziyayian	(35. 657211, 51. 359457)
6	Imam-Khomeini	(35.707989, 51.380590)	13	Shahid Fayaz Bakhsh	(35. 675421, 51. 265177)
7	Shariat Razavi	(35.675807, 51.328461)	14	Firooz-Abadi	(35. 594403, 51. 436547)

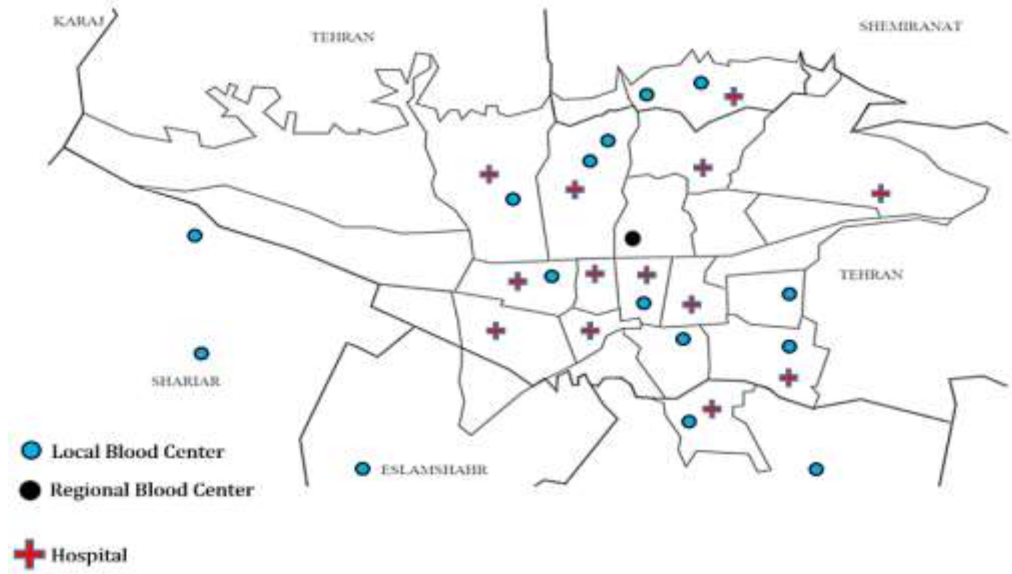

Figure 3. Geographical dispersion and location of the concerned blood supply chain network facilities and hospitals

Regarding the allocated budget to facilitate blood production process as well as professional experts' opinions, to assure the responsiveness and reliability of the concerned network for the process blood production, three supplementary blood centers (SBCs) should be selected from the current LBCs illustrated in Figure 2. Nevertheless, it is expected that the blood network goes under a great risk due to striking disruption in a single regional blood center.

The grey-based TOPSIS methodology applied to the case data

In this subsection, for further illuminating the grey numbers along with TOPSIS, the notations are firstly introduced, as well as the grey decision table to select supplementary blood production center. Given a database of LBCs for SBCs (a Grey table), $T = (A, C, V)$, where $A = \{A_1, A_2, \ldots A_n\}$ is a set of n alternatives for SBCs called the universe, and $C = \{C_1, C_2, \ldots C_m\}$ is a set of m attributes for the SBCs.

In the investigated case study, considering six attributes $C = \{C_j, j = 1, 2, 3, \cdots 6\}$, $A = \{A_i, i = 1, 2, \cdots, 15\}$ (i.e. fifteen LBCs for SBCs) considering six attributes $C = \{C_j, j = 1, 2, 3, \cdots 6\}$. Concerning the attributes, three categories are assumed: environmental, economic/business, and social attributes, that each category is divided into two sections, i.e. B1 and B2, E1 and E2, and S1, S2, respectively. Table 4 denotes these attributes.

Among the multiple criteria affecting the supplementary blood centers selection, qualitative attributes including Flexibility, Quality, Management system, Transportation alternatives, Health and Safety, and Labor skills are significant and albeit challenging. In the present study, these factors are considered for selecting best fit supplementary blood centers according to the experts' knowledge and viewpoint. Therefore, extraction of sustainable factors and the value of each factor has been defined based on the professional field experts' knowledge in Tehran Blood Transfusion Organization (TBTO).

Table 4. attributes for selecting SBCs

Categories	Factors
Business metrics	Flexibility (B1)
	Quality (B2)
Environmental metrics	Management system (E1)
	Transportation alternatives (E2)
Social metrics	Health and Safety (S1)
	Labor skills (S2)

Step 1
Evaluating and assigning the importance level of each decision-maker

The importance level assigned to each decision-maker (DM), as well as their opinions as input, is obtained by the grey scale variable vector $\otimes D^k = \left[\underline{D^k}, \overline{D^k}\right]$. As there are four DMs in the present case study ($k \in K$and $K = 1, \ldots, 5$), the following grey scale importance level is available: $\otimes D^1 = \left[\underline{D^1}, \overline{D^1}\right] = [0.5, 0.7]$ (DM $D1$ is at the ' Moderately Important' level), $\otimes D^2 = [0.7, 0.9]$ ('Important' level for DM $D2$), $\otimes D^3 = [0.5, 0.7]$ ('Moderately Important' level for DM $D3$), $\otimes D^4 = [0.9, 1.0]$ ('Very Important' level for DM $D4$), and $\otimes D^5 = [0.7, 0.9]$ ('Important' level for DM $D5$).

Step 2
Acquiring the relative importance of each attribute from each decision-maker' opinion and assigning scale values

According to Table 5, each decision-maker k evaluates each attribute j through assigning textual perceptual scores ranging from very low to very high.

Table 5. Grey scale variable matrix for initial evaluations of factor importance by each decision-maker

Decision Maker	Business metrics		Environmental metrics		Social metrics	
	B1	B2	E1	E2	S1	S1
D1	H	H	M	VH	VH	M
D2	VH	H	VH	M	SH	M
D3	M	M	M	H	H	SH
D4	VH	VH	H	VH	VH	M
D5	M	SH	H	SH	M	M

The outcomes of the evaluation lead to the grey scale variable matrix $\otimes r = \otimes r_j^k = \left[\underline{r_j^k}, \overline{r_j^k}\right], j = 1, \ldots, m.$

Regarding Table 6, the following seven-level grey scales for the factors importance evaluation are tabulated.

Table 6. The scale of the attribute level of importance ⊗r

Scale	⊗ r
Very High (VH)	[0.9,1.0]
High (H)	[0.7,0.9]
Somewhat High (SH)	[0.6,0.7]
Moderate (M)	[0.4,0.6]
Somewhat Moderate (SM)	[0.3,0.4]
Low (L)	[0.1,0.3]
Very Low (VL)	[0.0,0.1]

Regarding Tables 5 and 6, the grey scale importance values $\otimes r_j^k$ for each attribute j and DM k are determined. As an example, for B1 (i.e. $j = 1$) and within all DMs $(k = 1, \dots, 5)$, the grey scale importance values are assumed to be $r_1^1 = [0.7,0.9]$, $r_1^2 = [0.9,1.0]$, $r_1^3 = [0.4,0.6]$, $r_1^4 = [0.9,1.0]$, $r_1^5 = [0.4,0.6]$.

Step 3

Adjusting the final attribute weight level $\otimes \tilde{r}_j$ using DM information

Using expression (11), for each attribute j and DM $k(\otimes \tilde{r}_j^k)$, the adjusted attribute importance of weight can be determined:

$$\otimes \tilde{r}_j^k = \otimes r_j^k . \otimes D^k = \left[\min(\underline{r_j^k}\underline{D^k}, \underline{r_j^k}\overline{D^k}, \overline{r_j^k}\underline{D^k}, \overline{r_j^k}\overline{D^k}) \quad (11)$$

To have a better understanding, for example $\otimes \tilde{r}_1^1 = \otimes r_1^1 \times \otimes D^1 = [\min(0.5 \times 0.7, 0.5 \times 0.9, 0.7 \times 0.7, 0.7 \times 0.9), \max(0.5 \times 0.7, 0.5 \times 0.9, 0.7 \times 0.7, 0.7 \times 0.9) = [0.35, 0.63]$ denotes the adjusted attribute importance weight for B1 ($j = 1$) and decision maker 1 ($k = 1$). It is imperative to note that $\underline{r_j^k}\underline{D^k}$ and $\overline{r_j^k}\overline{D^k}$ are used for the lowest and highest value of grey scale, respectively, in all cases. Generally, when it comes to a negative value, the more generic equation is required. Thus, the average importance weight variable for each DM can be obtained using the following expression:

$$\otimes \tilde{r}_j = \frac{1}{k}[\otimes \tilde{r}_j^1 + \otimes \tilde{r}_j^2 + \dots + \otimes \tilde{r}_j^k] \quad (12)$$

Table 7 illustrates the final adjusted importance weight of each attribute in grey scale values.

Step 4

Determining the performance levels of alternatives on various factors

For each mentioned attribute of LBCs, the attribute value is determined based on the group of decision-makers' opinion. As mentioned before, each decision maker assigns a textual perceptual score ranging from very poor to very good for each LBCs as well as attributes. In this study, the seven-level scale used as demonstrated in Table 8. Better to say, for each attribute (j) for each LBC (i), a grey scale score $\otimes u$ will be assigned by each decision maker (k). The results of textual assignment for each LBC are shown in Table 9.

Table 7. The adjusted attribute importance values $\otimes \tilde{w}_j$

Factor	Average Adjusted Importance Weight
B1	[0.45, 0.70]
B2	[0.45, 0.70]
E1	[0.43, 0.69]
E2	[0.47, 0.70]
S1	[0.46, 0.70]
S2	[0.28, 0.52]

Table 8. The scale of attribute ratings $\otimes u$

Scale	$\otimes \boldsymbol{u}$
Very Good (VG)	[0.9,1.0]
Good (G)	[0.6,0.9]
Somewhat Good (SG)	[0.5,0.6]
Fair (F)	[0.4,0.5]
Somewhat Fair (SF)	[0.3,0.4]
Poor (P)	[0.1,0.3]
Very poor (VP)	[0,0.1]

Table 9. Evaluation of each LBC on factors by DMs

	DM 1						DM 2						DM 3						DM 4						DM 5					
	B1	B2	E1	E2	S1	S2	B1	B2	E1	E2	S1	S2	B1	B2	E1	E2	S1	S2	B1	B2	E1	E2	S1	S2	B1	B2	E1	E2	S1	S2
Sadeghieh	VG	G	G	SF	F	VG	G	VG	VG	VP	SF	G	G	G	G	VG	SF	VG	SG	G	F	G	VP	P	SF	G	F	SG	VP	G
Chizar	SF	VG	G	SG	SG	SG	SG	G	VG	F	G	F	SF	G	SF	SF	G	G	G	F	SF	G	SF	G	G	G	VP	G	VP	G
Shohada ye Tajrish	VG	P	G	P	VP	SG	G	SF	SF	G	G	P	G	F	SF	SG	VG	SF	G	VP	SG	P	SG	VG	SG	SG	G	SG	G	G
Shahid Rajae	F	SF	SF	VP	SG	G	SG	G	SF	VP	SF	VG	G	G	G	G	VG	F	VG	P	SF	G	SF	G	G	SG	SF	SG	VP	VG
Milad	SF	P	G	P	G	SF	G	SF	G	SG	G	G	G	G	SF	F	SF	G	SF	SF	SG	G	VP	VG	SG	F	VP	G	F	G
Azadi	G	F	VG	G	SG	VP	VP	P	F	VP	VG	G	G	G	VG	VG	G	G	SG	SF	G	SF	G	G	F	SG	SF	VP	P	SG
Emam Khomeini	G	VG	G	VG	SG	VG	SF	G	VP	SF	G	SG	VG	F	SF	VP	VG	G	VG	G	P	G	F	VP	G	VP	SF	G	SF	VG
Shahre-Rey	G	P	G	SF	VP	G	VP	VP	VP	SG	VP	VP	G	VG	G	SF	VG	SG	SF	SF	G	SF	F	P	VP	P	VP	SG	F	G
Varamin	SF	SF	G	G	VG	SG	P	SG	P	G	P	SF	SG	SG	G	SG	VG	SF	P	P	VP	G	G	SF	G	G	VG	G	SG	G
Shahriar	SF	G	G	SF	F	G	VP	SF	VG	G	SF	P	P	SF	VG	SG	P	G	SG	VP	SG	SF	VG	G	G	SG	VP	G	G	SF
Afsarieh	G	P	G	SG	VP	P	G	VP	VG	SF	VG	G	G	F	G	G	G	SG	SF	G	VG	F	VG	SF	F	G	G	SG	SG	SG
Piroozi	G	VG	SF	SF	G	P	VP	G	G	SF	VG	SF	SG	VG	SF	VG	G	SG	G	G	G	SF	SG	G	VG	G	P	G	SG	F
Khorasan	SF	G	F	G	F	F	P	VG	SG	VG	SF	VG	VG	G	G	F	SF	G	SG	G	VG	G	VG	VG	SG	G	G	G	P	G
Robat-Karim	G	SF	SF	SG	SF	VG	P	G	F	F	G	SF	SF	SG	SF	VG	SG	VG	SF	G	VG	SG	G	SF	G	G	SG	F	G	G
Shahre-Ghods	G	G	G	G	P	SG	P	G	VP	P	VP	P	G	VG	VP	G	G	SG	G	VG	P	G	G	G	P	G	G	F	G	SF

Step 5
Calculating unadjusted aggregated grey values performance levels of alternatives for each attribute

In this step, for each major attribute, a single unadjusted evaluation of the aggregated (within the group of decision-maker) grey values is determined. As the group of decision-makers encompasses K people, the aggregated grey values for LBC i factor j, $\otimes u_{ij}$ is obtained using the following expression:

$$\otimes u_{ij} = \frac{1}{k}\sum_{k=1}^{K} u_{ij}^{k} . \otimes D^{k}, \quad \forall i, j \qquad (13)$$

where $\otimes u_{ij}$ $(i = 1,2, \dots, n; j = 1,2, \dots, m; k = 1,2 \dots, K)$ is the attribute rating value of the K^{th} decision-maker for attribute j for LBC i, and can be defined by the grey number $\otimes u_{ij}^{k} = \left[\underline{u_{ij}^{k}}, \overline{u_{ij}^{k}}\right]$. As an example of the average importance weight variable calculation, the grey value for LBC 1, factor 1 ($\otimes u_{11}^{1}$) is:

$$\otimes u_{11}^{1} = \frac{1}{5}[(0.9 * 0.5 + 0.6 * 0.7 + 0.6 * 0.5 + 0.5 * 0.9 + 0.3 * 0.7), (1.0 * 0.7 + 0.9 * 0.9 + 0.9 * 0.7 + 0.6 * 1.0 + 0.4 * 0.9)] = [0.366, 0.620]$$

In this regard, Table 10 shows the summary of raw (non-adjusted) total grey factor LBCs scores.

Table 10. Unadjusted aggregate grey scores of LBCs on factors ($\otimes u_{ij}$)

	B1	B2	E1	E2	S1	S1
Sadeghieh	[0.366 ,0.620]	[0.438 ,0.774]	[0.374 ,0.622]	[0.312 ,0.538]	[0.144 ,0.312]	[0.366 ,0.620]
Chizar	[0.322 ,0.562]	[0.390 ,0.690]	[0.284 ,0.496]	[0.328 ,0.572]	[0.262 ,0.506]	[0.322 ,0.562]
Shohadaye Tajrish	[0.412 ,0.716]	[0.180 ,0.352]	[0.306 ,0.536]	[0.232 ,0.456]	[0.358 ,0.626]	[0.412 ,0.716]
Shahid Rajae	[0.416 ,0.666]	[0.262 ,0.512]	[0.228 ,0.406]	[0.262 ,0.510]	[0.250 ,0.430]	[0.416 ,0.666]
Milad	[0.298 ,0.532]	[0.222 ,0.410]	[0.278 ,0.518]	[0.312 ,0.562]	[0.248 ,0.494]	[0.298 ,0.532]
Azadi	[0.280 ,0.516]	[0.238 ,0.438]	[0.386 ,0.622]	[0.232 ,0.454]	[0.358 ,0.624]	[0.280 ,0.516]
Emam Khomeini	[0.438 ,0.700]	[0.336 ,0.606]	[0.164 ,0.368]	[0.334 ,0.596]	[0.338 ,0.558]	[0.438 ,0.700]
Shahre-Rey	[0.202 ,0.440]	[0.182 ,0.370]	[0.256 ,0.540]	[0.254 ,0.408]	[0.242 ,0.426]	[0.202 ,0.440]
Varamin	[0.196 ,0.416]	[0.252 ,0.470]	[0.278 ,0.546]	[0.386 ,0.714]	[0.372 ,0.622]	[0.196 ,0.416]
Shahriar	[0.228 ,0.434]	[0.220 ,0.422]	[0.380 ,0.620]	[0.302 ,0.544]	[0.338 ,0.546]	[0.228 ,0.434]
Afsarieh	[0.314 ,0.584]	[0.256 ,0.508]	[0.492 ,0.794]	[0.294 ,0.490]	[0.428 ,0.656]	[0.314 ,0.584]
Piroozi	[0.358 ,0.624]	[0.456 ,0.784]	[0.266 ,0.508]	[0.300 ,0.510]	[0.406 ,0.660]	[0.358 ,0.624]
Khorasan	[0.294 ,0.478]	[0.438 ,0.774]	[0.416 ,0.666]	[0.418 ,0.718]	[0.288 ,0.452]	[0.294 ,0.478]
Robat-Karim	[0.242 ,0.478]	[0.356 ,0.644]	[0.348 ,0.510]	[0.342 ,0.524]	[0.356 ,0.644]	[0.242 ,0.478]
Shahre-Ghods	[0.256 ,0.540]	[0.480 ,0.790]	[0.186 ,0.444]	[0.298 ,0.576]	[0.276 ,0.564]	[0.256 ,0.540]

Step 6

Determining adjusted aggregated grey values performance levels of LBCs for each attribute

Regarding the aggregated factor weight scores obtained in step 5, the scores for each LBC *i* ($\otimes u_{ij}$) with adjusted attribute j and importance weighting ($\otimes \tilde{u}_j$) should be adjusted in this step. Expression (14) calculates the adjusted total factor weight scores $\otimes u_{ij}$:

$$\otimes \tilde{u}_{ij} = \otimes \tilde{r}_j . \otimes u_{ij} = \begin{bmatrix} \min(\underline{\tilde{r}_j u_{ij}}, \underline{\tilde{r}_j} \overline{u_{ij}}, \overline{\tilde{r}_j} \underline{u_{ij}}, \overline{\tilde{r}_j} \overline{u_{ij}}), \\ \max(\underline{\tilde{r}_j u_{ij}}, \underline{\tilde{r}_j} \overline{u_{ij}}, \overline{\tilde{r}_j} \underline{u_{ij}}, \overline{\tilde{r}_j} \overline{u_{ij}}) \end{bmatrix} \quad (14)$$

For example, the adjusted grey value for the first business factor for LBC 1's is:

$$\otimes \tilde{u}_{11} = \otimes \tilde{r}_1 . \otimes u_{11}$$

$$= [min(0.366 \times 0.450, 0.366 \times 0.700, 0.620 \times 0.450, 0.620 \times 0.700), max(0.366 \times 0.450, 0.366 \times 0.700, 0.620 \times 0.450, 0.620 \times 0.700)] = [0.166, 0.433]$$

Table 11 shows a summary of the adjusted aggregate grey factor scores results.

Table 11. Adjusted grey scores of LBCs on factors ($\otimes \tilde{u}_{ij}$)

	B1	B2	E1	E2	S1	S1
Sadeghieh	[0.166 ,0.433]	[0.199 ,0.540]	[0.161 ,0.429]	[0.144 ,0.377]	[0.067 ,0.218]	[0.104 ,0.344]
Chizar	[0.146 ,0.392]	[0.177 ,0.482]	[0.122 ,0.342]	[0.152 ,0.400]	[0.121 ,0.354]	[0.102 ,0.333]
Shohadaye Tajrish	[0.187 ,0.500]	[0.082 ,0.246]	[0.132 ,0.370]	[0.107 ,0.319]	[0.165 ,0.438]	[0.097 ,0.288]
Shahid Rajae	[0.189 ,0.465]	[0.119 ,0.357]	[0.098 ,0.280]	[0.121 ,0.357]	[0.116 ,0.301]	[0.131 ,0.381]
Milad	[0.135 ,0.371]	[0.101 ,0.286]	[0.120 ,0.357]	[0.144 ,0.393]	[0.115 ,0.346]	[0.119 ,0.366]
Azadi	[0.127 ,0.360]	[0.108 ,0.306]	[0.166 ,0.429]	[0.107 ,0.318]	[0.165 ,0.437]	[0.094 ,0.320]
Emam Khomeini	[0.199 ,0.489]	[0.153 ,0.423]	[0.071 ,0.254]	[0.154 ,0.417]	[0.156 ,0.391]	[0.103 ,0.318]
Shahre-Rey	[0.092 ,0.307]	[0.083 ,0.258]	[0.110 ,0.373]	[0.117 ,0.286]	[0.112 ,0.298]	[0.064 ,0.252]
Varamin	[0.089 ,0.290]	[0.114 ,0.328]	[0.120 ,0.377]	[0.178 ,0.500]	[0.172 ,0.435]	[0.074 ,0.235]
Shahriar	[0.104 ,0.303]	[0.100 ,0.295]	[0.163 ,0.428]	[0.140 ,0.381]	[0.156 ,0.382]	[0.081 ,0.289]
Afsarieh	[0.143 ,0.408]	[0.116 ,0.355]	[0.212 ,0.548]	[0.136 ,0.343]	[0.198 ,0.459]	[0.076 ,0.247]
Piroozi	[0.163 ,0.436]	[0.207 ,0.547]	[0.114 ,0.351]	[0.139 ,0.357]	[0.188 ,0.462]	[0.076 ,0.242]
Khorasan	[0.133 ,0.334]	[0.199 ,0.540]	[0.179 ,0.460]	[0.193 ,0.503]	[0.133 ,0.316]	[0.134 ,0.382]
Robat-Karim	[0.110 ,0.334]	[0.162 ,0.450]	[0.150 ,0.352]	[0.158 ,0.367]	[0.164 ,0.451]	[0.102 ,0.308]
Shahre-Ghods	[0.116 ,0.377]	[0.218 ,0.551]	[0.080 ,0.306]	[0.138 ,0.403]	[0.128 ,0.395]	[0.075 ,0.246]

Step 7: Determining the grey ideal and nadir LBCs

As the grey valuation has already been normalized, there is no requirement to normalize the decision matrix in an additional step for TOPSIS methodology. In the presented case, all attributes are positive measure (the higher the value, the better the attribute situation); thus, the ideal and nadir solution for each attribute can be determined. First, using the following expression (maximum factor value in the set), the most grey 'ideal' reference LBC alternative $O^{+}(\otimes\tilde{u})$ is determined:

$$O^{+}=\{\otimes\tilde{u}_j^{+}\}=\{\underline{\tilde{u}_j^{+}},\overline{\tilde{u}_j^{+}}\}=\{(\max\underline{\tilde{u}_{ij}},\max\overline{\tilde{u}_{ij}})\},\quad j=1,2,\dots,m \tag{15}$$

Regarding the above approach, the most grey 'ideal' reference LBC alternative O^{+} and its values are:

O^{+}
$=\{[0.199,0.500],[0.218,0.547],[0.212,0.548],[0.193,0.507],[0.198,0.462],[0.134,0.382]\}$

Similarly, the most grey 'nadir' reference LBC alternative $O^{-}(\otimes\tilde{u})$ is determined:

$$O^{-}=\{\otimes\tilde{u}_j^{-}\}=\{\underline{\tilde{u}_j^{-}},\overline{\tilde{u}_j^{-}}\}=\{(\min\underline{\tilde{u}_{ij}},\min\overline{\tilde{u}_{ij}})\},\quad j=1,2,\dots,m \tag{16}$$

Thus, the most grey 'nadir' reference LBC alternative O^{-} is calculated as:

O^{-}
$=\{[0.089,0.290],[0.082,0.246],[0.071,0.254],[0.107,0.286],[0.067,0.218],[0.064,0.235]\}$.

Step 8: Calculating the distance for grey separation measure

As mentioned earlier, regarding TOPSIS separation measure expressions (8) and (9), expression (17) and (18) indicate a new grey separation measure for an object and 'ideal' and 'nadir' alternative for each attribute.

$$\otimes\rho_i^{+}(O^{+},O_i)=\sum_{j=1}^{m}(\otimes\tilde{u}_j^{+}-\otimes\tilde{u}_{ij})=\sum_{j=1}^{m}((\underline{\tilde{u}_j^{+}}-\underline{\tilde{u}_{ij}}),(\overline{\tilde{u}_j^{+}}-\overline{\tilde{u}_{ij}})) \tag{17}$$

$$\otimes\rho_i^{-}(O^{-},O_i)=\sum_{j=1}^{m}(\otimes\tilde{u}_{ij}-\otimes\tilde{u}_j^{-})=\sum_{j=1}^{m}((\underline{\tilde{u}_{ij}}-\underline{\tilde{u}_j^{-}}),(\overline{\tilde{u}_{ij}}-\overline{\tilde{u}_j^{-}})) \tag{18}$$

Following calculation is an illustrative example for $\otimes\rho_1^{+}$ according to expression (17):

$$\otimes\rho_1^{+}=\sum_{j=1}^{m}(\otimes\tilde{u}_j^{+}-\otimes\tilde{u}_{ij})=[(0.199-0.166),(0.500-0.433)]+\sum_{j=2}^{m}(\otimes u_j^{+}-\otimes\tilde{u}_{ij})=[0.033,0.067]+\sum_{j=2}^{m}(\otimes\tilde{u}_j^{+}-\otimes\tilde{u}_{ij})=[0.313,0.605]$$

Analogously, the following calculation presents an illustrative example for $\otimes\rho_1^{-}$ according to expression (18):

$$\otimes\rho_1^{-}=\sum_{j=1}^{m}(\otimes\tilde{u}_{ij}-\otimes\tilde{u}_j^{-})=[(0.166-0.092),(0.433-0.290)]+\sum_{j=2}^{m}(\otimes\tilde{u}_{ij}-\otimes\tilde{u}_j^{-})=[0.074,0.143]+\sum_{j=2}^{m}(\otimes\tilde{u}_{ij}-\otimes u_j^{-})=[0.361,0.812]$$

Table 12 shows the LBC grey separation distances from the ideal and nadir solution for each candidate location.

Table 12. The relative closeness of LBCs and ranking

	ρ_i^{+}	ρ_i^{-}	K_i	Ranking
Sadeghieh	[0.313 ,0.605]	[0.361 ,0.812]	[0.321, 0.722]	5
Chizar	[0.334 ,0.643]	[0.340 ,0.774]	[0.307, 0.699]	7
Shohadaye Tajrish	[0.384 ,0.785]	[0.290 ,0.632]	[0.285, 0.622]	9
Shahid Rajae	[0.38 0,0.805]	[0.294 ,0.612]	[0.296, 0.617]	8
Milad	[0.420 ,0.827]	[0.254 ,0.590]	[0.251, 0.584]	13
Azadi	[0.387 ,0.776]	[0.287 ,0.641]	[0.279, 0.624]	10
Emam Khomeini	[0.318 ,0.654]	[0.356	[0.329, 0.706]	6

	ρ_i^+	ρ_i^-	K_i	Ranking
		,0.763]		
Shahre-Rey	[0.576 ,1.172]	[0.098 ,0.245]	[0.119, 0.298]	15
Varamin	[0.407 ,0.781]	[0.267 ,0.636]	[0.256, 0.610]	12
Shahriar	[0.410 ,0.868]	[0.264 ,0.549]	[0.275, 0.572]	11
Afsarieh	[0.273 ,0.586]	[0.401 ,0.831]	[0.363, 0.753]	3
Piroozi	[0.267 ,0.551]	[0.407 ,0.866]	[0.359, 0.764]	2
Khorasan	[0.183 ,0.411]	[0.491 ,1.006]	[0.413, 0.846]	1
Robat-Karim	[0.308 ,0.684]	[0.366 ,0.733]	[0.352, 0.704]	4
Shahre-Ghods	[0.399 ,0.668]	[0.275 ,0.749]	[0.240, 0.652]	14

Step 9: The grey relative closeness value from the ideal solution is determined

Using expression (19), the grey relative distance measure $\otimes K_i$ for an alternative O_i is calculated:

$$\otimes K_i = \frac{\otimes \rho_i^-}{\otimes \rho_i^- + \otimes \rho_i^+} = \frac{(\underline{\rho_i^-}, \overline{\rho_i^-})}{(\underline{\rho_i^+} + \underline{\rho_i^-}, \overline{\rho_i^+} + \overline{\rho_i^-})} = \left[\frac{\underline{\rho_i^-}}{\overline{\rho_i^+} + \overline{\rho_i^-}}, \frac{\overline{\rho_i^-}}{\underline{\rho_i^+} + \underline{\rho_i^-}}\right] \quad (19)$$

Regarding Table 9, which have summarized the final comparative distances $\otimes K_i$, $\otimes K_1$ is determined as follows:

$$\otimes K_1 = \frac{\otimes \rho_1^-}{\otimes \rho_1^- + \otimes \rho_1^+} = \left[\frac{0.361}{0.812 + 0.605}, \frac{0.812}{0.812 + 0.605}\right] = [0.321, 0.722]$$

In the form of interval grey numbers, the grey relative closeness values for each LBC can be obtained. For example, [0.321, 0.722] for LBC 1 and [0.307, 0.699] for LBC 2. Regarding these intervals, it looks almost difficult to directly judge whether LBC 1 or LBC 2 is better. In this regard, there was a traditional method that the interval grey number was converted into a crisp one; however, this conversion caused losses in information, such as the breadth of the interval of numbers. To tackle this problem, a degree of likelihood measure will be introduced in the next step.

Step 10: Ranking the LBCs using the degree of likelihood

In this step, the degree of likelihood is introduced to extend the TOPSIS evaluation that which LBC is better than the others. By expression (5), the degree of likelihood pairwise comparison of any two LBCs is first determined. Afterward, the degree of likelihood for each LBC can be obtained by establishing a matrix using expression (20):

$$P_{n.n} = p(\otimes K_i \geq \otimes K_h)_{n.n} \quad i, h = 1, \dots, n \quad (20)$$

For example, we have $\otimes K_1$= [0.321, 0.722] and $\otimes K_2$ = [0.307, 0.699] for the grey relative closeness level of LBC 1 and LBC 2, respectively. it denotes that the degree of likelihood for LBC 1 is bigger than LBC 2, that is:

$$p(\otimes K_1 \geq \otimes K_2) = \frac{\overline{K_1} - \underline{K_2}}{\overline{K_1} - \underline{K_1} + \overline{K_2} - \underline{K_2}} = \frac{0.722 - 0.307}{0.401 + 0.392} = 52.3\% > 50\%$$

The above calculation shows that LBC1 is 55.8% more likely to be better than LBC2. Table 13 shows a matrix that includes the degree of likelihood that one alternative (LBC) is ranked higher than another. The higher degree of likelihood percentage guides one to order all LBCs. In other words, the value of T_i in descending order shows the priority of alternatives. Therefore, alternative LBC 13 with the score of [0.413, 0.846] is the most preferred alternative alongside 15 other alternatives in the universe set.

Table 13. The degree of likelihood that one alternative is better than another alternative matrix, %

	Sadeghieh	Chizar	Shohadaye Tajrish	Shahid Rajae	Milad	Azadi	Emam Khomeini	Afsarieh	Piroozi	Khorasan	Khorasan	Khorasan	Khorasan	Khorasan	Khorasan
Sadeghieh	0.5	0.523	0.592	0.59	0.642	0.594	0.505	1.04	0.617	0.64	0.454	0.45	0.371	0.491	0.59
Chizar	0.477	0.5	0.568	0.565	0.618	0.57	0.481	1.016	0.594	0.615	0.43	0.427	0.347	0.466	0.57
Shohadaye Tajrish	0.408	0.432	0.5	0.495	0.554	0.503	0.41	0.975	0.53	0.547	0.356	0.354	0.271	0.392	0.51
Shahid Rajae	0.41	0.435	0.505	0.5	0.56	0.508	0.413	0.996	0.535	0.553	0.357	0.355	0.271	0.394	0.51
Milad	0.358	0.382	0.446	0.44	0.5	0.45	0.359	0.908	0.477	0.49	0.306	0.305	0.223	0.339	0.46
Azadi	0.406	0.43	0.497	0.492	0.55	0.5	0.409	0.964	0.526	0.544	0.355	0.353	0.271	0.39	0.51
Emam Khomeini	0.358	0.382	0.446	0.44	0.5	0.45	0.359	0.908	0.477	0.49	0.306	0.305	0.223	0.339	0.46
Shahre-Rey	0.358	0.382	0.446	0.44	0.5	0.45	0.359	0.908	0.477	0.49	0.306	0.305	0.223	0.339	0.46
Varamin	0.495	0.519	0.59	0.587	0.641	0.591	0.5	1.056	0.616	0.639	0.447	0.444	0.362	0.486	0.59
Shahriar	0.0	0.0	0.025	0.004	0.092	0.036	0.0	0.5	0.079	0.048	0.0	0.0	0.0	0.0	0.1
Afsarieh	0.383	0.406	0.47	0.465	0.523	0.474	0.384	0.921	0.5	0.515	0.332	0.331	0.25	0.365	0.48
Piroozi	0.36	0.385	0.453	0.447	0.51	0.456	0.361	0.952	0.485	0.5	0.304	0.303	0.218	0.339	0.47
Khorasan	0.546	0.57	0.644	0.643	0.694	0.645	0.553	1.114	0.668	0.696	0.5	0.496	0.413	0.54	0.64
Robat-Karim	0.55	0.573	0.646	0.645	0.695	0.647	0.556	1.104	0.669	0.697	0.504	0.5	0.419	0.544	0.64
Shahre-Ghods	0.629	0.653	0.729	0.729	0.777	0.729	0.638	1.188	0.75	0.782	0.587	0.581	0.5	0.629	0.72

Sensitivity analysis

In this section, sensitivity analysis on three scenarios is presented to specify the solution robustness. In Table 14, sensitivity analysis on three scenarios has been done when only a portion of factors are considered for selecting SBCs. In the first scenario, in column three of Table 14, uses business metrics (Flexibility and Quality) only to evaluate the SBCs. The fourth column of Table 14 considers a scenario with only environmental metrics (Management system and transportation alternatives), while the fifth column, considers a scenario with only by the social metrics (Health and Safety and Labor skills) to measure the SBCs. In each column of Table 14 ranking of LBCs for selecting SBCs is presented. This result prepares another viewpoint on how a best fit candidate location for SBCs is selected by decision-makers.

Table 14. Results of the sensitivity analysis

	Initial Scenario (All factors)	Scenario 1 (Flexibility and Quality)	Scenario 2 (Management system and transportation alternatives)	Scenario 3 (Health and Safety and Labor skills)
Sadeghieh	5	3	5	14
Chizar	7	6	8	11
Shohadaye Tajrish	9	10	11	3
Shahid Rajae	8	7	15	9
Milad	13	12	9	8
Azadi	10	11	7	2
Emam Khomeini	6	2	13	6
Shahre-Rey	15	15	14	15
Varamin	12	13	3	10

	Initial Scenario (All factors)	Scenario 1 (Flexibility and Quality)	Scenario 2 (Management system and transportation alternatives)	Scenario 3 (Health and Safety and Labor skills)
Shahriar	11	14	4	12
Afsarieh	3	9	2	4
Piroozi	2	1	10	5
Khorasan	1	5	1	7
Robat-Karim	4	8	6	1
Shahre-Ghods	14	4	12	13

Conclusions

In this paper, we introduced grey number based TOPSIS as a multi-stage (multiple computational steps), multi-method (integration of multiple methods such as the grey number and TOPSIS), multi-metric (dealing with multidimensional attributes) method to evaluate and select alternatives using various factors and conceptual applications. This technique is a useful tool for managers, and researchers, who seek to evaluate alternative performance in various multi-criteria decision making studies.

Investigating blood supply chain performance, we utilized a real-data set from Tehran blood transfusion center for validating the proposed technique and providing managerial insight into operational execution, results, and validity. Generally, the proposed technique is found to provide relatively consistent results of top-performing alternatives when compared with the more complex and less intuitively appealing grey-rough set theory approach. A single aggregate and relative performance metric are determined for evaluating the best alternative or provide a ranking of alternatives.

The major contribution of this research is twofold, integrating Grey numbers with TOPSIS to tackle the uncertainty in location problem as well as selecting appropriate criteria for selecting supplementary blood centers. The comparison of the proposed method with the existing ones in the related literature reveals that the proposed method can appropriately embed the uncertainty in the MCDM problems in a practical manner, which the decision-makers can evaluate the attribute more accurately when the problem involved linguistic variables, as well as the process of proposed technique, is less time-consuming for decision-makers, experts, managers. There are some research realms to be discovered in the future. The proposed technique can be compared with another crisp one, fuzzy, and grey decision-making techniques. Also, the fuzzy method can be applied rather than a crisp one, and the obtained results can be compared. Finally, the model can be improved for group decision making incorporating different DMs to the process of decision making.

Authors' Contributions

SMRG contributed to study design, data collection and analysis and manuscript drafting. HMSM took part in interoretation of the results and drafting the manuscript. Both authors read and approved the final manuscript.

Competing Interests

The authors declare no competing interests.

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Please cite this article as:

Mohammad Reza Ghatreh Samani, Seyyed-Mahdi Hosseini-Motlagh. Evaluation and Selection of Most Preferable Supplementary Blood Centers in The Case of Tehran. Int J Hosp Res. 2018; 7 (4).