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The Use of Internet of Things and Big data in the Food Bank Supply Chain Problem: A Case Study of Tehran Municipal Districts

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Abstract

Today, due to financial crises and successive droughts, collecting and distributing food with high nutritional value and freshness for the homeless and low-income people has become a global issue. Therefore, most countries are trying to manage this issue by creating centers called food banks. The importance of the food bank issue has led to the modeling of the food bank network issue based on IoT and Big Data in this article. The problem of the studied food bank network consists of a set of donors, food banks and charities. In this network, donors provide food needed by charities for free. Food banks also distribute food collected from donors to charities. The purpose of presenting this model is to reduce the costs of the entire food bank network along with reducing the maximum unmet demand. The results of the model analysis on a case study in Iran show that with the reduction of the shortage in the network, the total costs increase. So that the results of the mathematical model in a case study in Tehran metropolis showed that three areas 11, 15 and 19 were selected as food banks and 12 vehicles are needed. In this study, 10 different efficient solutions were obtained with LP-Metrics and 11 different efficient solutions were obtained with Sum weight method (SWM). Also, if the amount of demand increases, in addition to increasing the shortage in the network, the costs related to transportation and providing food needed by charities have also increased.

Keywords: Food bank network, Inventory-allocation-routing, IoT, Big data

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1-Introduction

With the increase in world population and food prices, hunger and food insecurity are on the rise. Food insecurity continues to pose health-threatening concerns, while according to FAO (Food and Agriculture Organization), approximately 30% of food produced for human consumption is lost or wasted annually due to inefficient management of food supply chains, including improper storage and transportation activities (Kaviyani-Charati et al., 2022). In addition, food donation and distribution faces uncertainty, for example, the amount of food and the demand received at any time can be different. Other parameters, including distribution time, can be uncertain, which can affect food safety and demand satisfaction. In addition, food production consumes natural resources such as water and energy, so reducing food waste can save these natural resources for future generations (Albizzati et al., 2019). In this regard, the design of the food supply chain network can play a vital role by preventing the wastage of a significant amount of food, thereby reducing greenhouse gas emissions and increasing food security. Surplus food or food nearing its expiration date can be obtained and managed to meet food demand before it becomes waste using food banks and volunteer work.

Food banks operate with limited resources, depending mainly on donations and volunteer work. Therefore, it is very important for them to design and manage their supply chain network in an efficient and effective manner in order to ensure the greatest possible amount of food aid for people in need (Gonzalez-Torre et al., 2017). The current configuration of the food bank network is not the result of a strategic planning process, but has emerged through operational decisions and donation opportunities occasionally identified over the past 20 years (Martins et al., 2019). The supply chain network of food banks includes different parts from suppliers to end users such as warehouses, food donors and people in need, which can make it difficult to manage. In particular, the coordination of different sectors will be challenging when food or financial aid must be collected from donors in different locations and then repackaged and distributed to those in need (Wetherill et al., 2019; Sengul Orgut et al., 2016). Accordingly, the problem of designing the food bank chain network, with the reduction of waste and food insecurity, has received serious attention from researchers (Davis et al., 2014). To save surplus food, reduce food waste and improve food security, a food bank network can be used considering heterogeneous transportation facilities and cold chain storage.

One of the biggest challenges for companies today is the need to respond quickly to the ever-increasing amount of fluctuations in demand. Rapid developments in information technology (IT) have always led to innovations such as the Internet and its potential as a channel for collecting, transmitting and storing information. The emergence of the Internet has had a significant impact on the rapid growth of Internet-based information transfer between companies, suppliers, and their customers (Tavakkoli Moghaddam et al., 2021). The Internet has emerged as an effective tool to integrate and share information in the supply chain, at the same time it supports various coordination mechanisms throughout the supply chain. This itself increases the speed of decisions. Making quick decisions and speeding up the flow of materials through the integration and sharing of information flow increases the effectiveness and efficiency of the supply chain implementation, so that this increase in speed, when accompanied by no reduction in quality, can strengthen the supply chain and increase the satisfaction of those involved in the supply chain, as well as increase the preferences of end customers (Ogbuke et al., 2022). But there are always gaps between the flow of materials and also the flow of information in the supply chain. Because the flow of information cannot always reflect the wave of material flow in time and therefore it is impossible to understand the supply chain processes in a timely manner. The next generation of the Internet is called the Internet of Things, which is a very broad example of the Internet (Nozari et al., 2022). This can establish very extensive connections between objects and things and be a very valuable source for producing very large data in the supply chain. Using pervasive computing, this tool can fill the gap between objects in the material world as well as their representation in information systems (Sharma et al., 2020). Internet of Things tools can control the timely execution of supply chain processes. In this case, in addition to higher speed and accuracy, the efficiency and effectiveness of the supply chain can also be improved using the Internet of Things (Bocek et al., 2017). Therefore, providing an information architecture for the purpose of agility and emphasizing the purity of supply chain management can be of great importance. In recent years, information architecture for supply chain management has attracted the attention of the research community and industry. Today, decision support systems have become an essential tool for managing complex supply chains.

The importance of using the Internet of Things and big data analysis has led to the presentation of a model for the food bank supply chain based on IoT and Bog Data in Iran in this article. Therefore, in this research, a model is presented to determine the sources of big data production in the supply chain of the food bank, and finally, the mathematical model is designed with the aim of reducing the costs of the entire supply chain network and reducing the maximum lack of demand in order to increase the efficiency of the supply chain. The mathematical model is presented and its combination with the supply chain agility framework is based on the Internet of Things in order to achieve the selection of the best route for food distribution. This model also shows the optimal allocation of food flow and the amount of stored food.

This article is compiled in six parts. In the second part, a review of the research literature and the background of the research related to the subject has been done. In the third part, the food bank network model based on IoT and Big Data has been presented. In the fourth part, the solution methods are introduced and in the fifth part, the model results are analyzed. In this section, a real case study has been done. In the sixth section, the conclusions of the research have been discussed.

2-Literature Review

In this section, the literature review is discussed and the most important researches in this field are presented. Yang (2018) studied a sequential resource allocation problem in a non-profit organization. He designed a model with a focus on maximizing justice and reducing waste, for designing the optimal visit route, and also designed an experiment to evaluate and analyze the performance of this algorithm. Wetherill et al. (2019) conducted a study to describe best practices and strategies for advancing nutrition-focused food banking in the United States. They used qualitative interviews to obtain information about food banking practices and processes. Chen et al. (2021) considered a vehicle routing problem with the objective of minimizing the traveled distance and considering constraints such as capacity and transit time. They investigated the model on the provision of food bank services and the results showed that by modifying the vehicle's route, 94.4% of customers can benefit from food bank services.

Unal et al. (2021) used machine learning to analyze big data and the Internet of Things to analyze complex supply chains. They also presented a practical approach to integrate blockchain with machine memory to provide privacy and secure big data analytics services. In a study, Mandal et al. (2021) presented a decision support model for collectors that is able to reduce food waste by allocating donated food items from retailers to food banks, and also maximize the collector's profitability and minimize environmental impacts. Kaviyani-Charati et al. (2022) presented a mathematical model in order to design the supply chain of a non-profit food bank, which takes into account the sustainability factors in the multi-objective model, and takes into account cold and conventional facilities and fleet for all types of food. They conducted a real case study in the city of Tehran, taking into account many uncertain parameters and time constraints. Nozari et al. (2022) modeled a multi-depot vehicle routing model where demand and transportation costs were considered as fuzzy numbers. They used fuzzy stable method to control the model and fuzzy numbers. They also used Neutrosophic fuzzy method to solve the mathematical model. Sun and Ali (2022) conducted a systematic review to investigate how IoT and blockchain can help address the challenges facing current pharmaceutical supply chains (PSCs). Sosenko et al. (2022) collected a set of data between 2011 and 2019 containing information on the number of food banks and the volume of parcels in the network through 325 local authorities and created an information panel. They predicted the number of food parcels distributed by food banks using a quasi-experimental approach. Davila-Pena et al. (2023) presented a new formulation for the routing problem where the available fleet consists of trucks and trailers. Since solving the model for large samples was computationally expensive, they introduced and implemented a two-phase heuristic algorithm. The algorithm was tested on 21 samples. The results proved its effectiveness. Wang et al. (2023) investigated the bi-objective optimization problem with stochastic demand to achieve the Pareto optimal solution to minimize operational cost and maximize customer satisfaction. They presented a new evaluation method to measure customer satisfaction under the influence of time windows. Ghahremani-Nahr et al. (2023) presented a food bank network in order to minimize total costs, maximize the value of the food basket and maximize the freshness of food. They used meta-heuristic algorithms and Echelon constraint method to solve their model. Also, due to the indeterminacy of the model, they used the stable-fuzzy method to control their parameters. Hashemi-Amiri et al. (2023) proposed a bi-objective optimization model for the problem of supplier selection, scheduling and integrated routing for the supply chain of a three-level perishable product. Their goal was to reduce the risks of demand and supply uncertainty and to enhance distribution-related decisions by simultaneously optimizing total network costs and supplier reliability.

The importance of considering the design of the food bank supply chain network has led to the consideration of various factors, including strategic and tactical decisions for this area. Studying the literature on the subject shows that maximum provision of food for charities and the homeless is one of the main concerns of the government as the founder of these networks. Therefore, considering the importance and position of the food bank in providing and distributing high quality food for charitable institutions and the homeless, in this article, the problem of the food bank supply chain network is designed with the aim of minimizing the total costs and minimizing the maximum shortage of food. On the other hand, the supply and supply of food in the food bank network is a main issue in the design of the supply chain network. Usually, the amount of food supply by donors or the amount of demand of charitable institutions is different in each period of time. This information can lead to instability in the food bank supply chain network. Therefore, the use of IoT and Big data to solve this issue is suggested in this article. The integration of IoT tools to accelerate the collection of Big Data and analysis with the help of decision-based methods leads to the improvement of supply chain management.

3-Food bank supply chain based on IoT and Big Data

As stated in the previous section, the importance of food management from collecting food from donors to distributing it to charities has led to designing a model for food bank supply chain based on IoT and Big Data in this section. In order to achieve the food bank supply chain based on IoT and Big Data, first, all sources of big data production in the food bank supply chain have been extracted by studying the subject literature and relevant research background. Then, based on the 4-stage architecture of the Internet of Things (virtuality, sensitivity to the market, network-oriented and process integration), the food bank supply chain model has been presented. Since today, due to the reduction of food raw materials, high transportation costs, successive droughts, etc., the effective use of IoT has led to the use of software platforms by restaurants, caterers, food banks, and charities. This platform has led to the collection of information from different levels of the food bank supply chain network. Intelligent agents and information technology are also widely used as a platform for the production and storage of big data in food bank supply chain management systems. Since IoT is one of the most important sources of big data generation, the use of this tool can have a significant impact on food bank supply chain management. Although the use of special tools may lead to an increase in information and its use for food bank managers, this will be inefficient in the long run. Therefore, a coherent and single framework should be designed for the structures and creation of different data flows. The various components of a food bank supply chain are donors, food banks and charities. Considering these levels of the supply chain network with the 4-stage architecture of IoT has led to the creation of a framework according to Figure (1). The first issue in using the stated framework is the possibility of extensive communication between the components of the food bank supply chain and the existence of a technical platform and facilities for sharing information in real time.

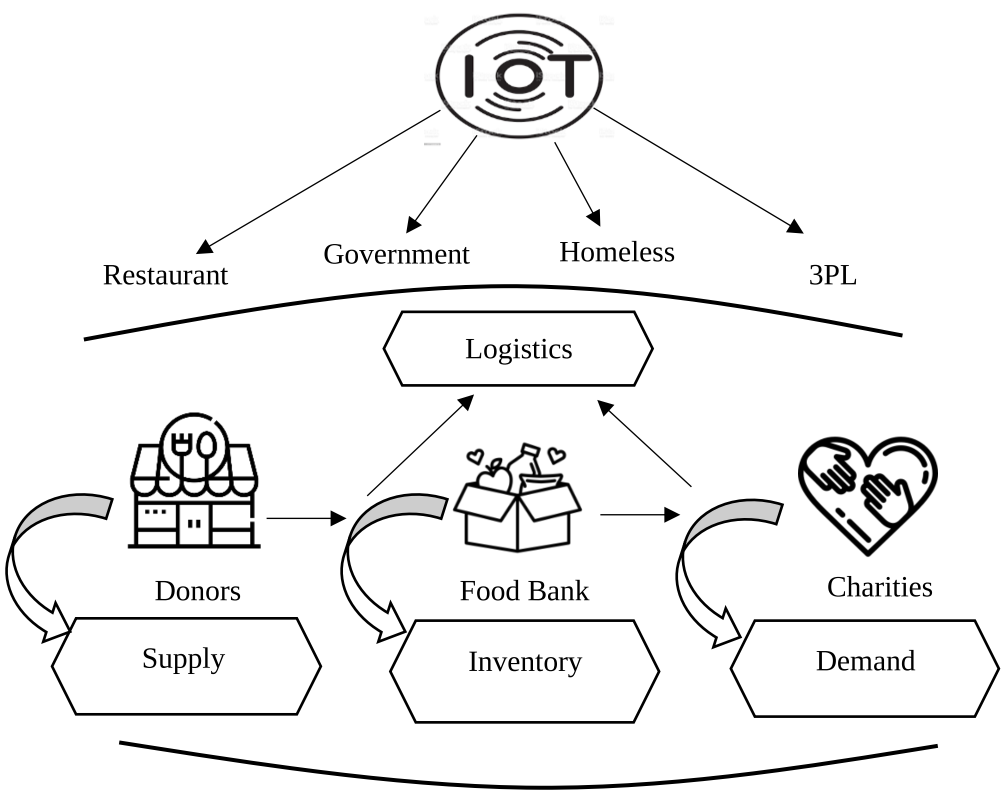

Figure 1. Sources of Big Data production in the food bank supply chain

To implement the food bank supply chain based on IoT and Big Data, it is necessary to coordinate the data entry path with the 4-step architectural components and then integrate it into a logical framework. Intelligent agents and information technology can communicate with other agents or humans and facilitate the transfer of information at different levels of the food bank supply chain network. Therefore, it can be said that the use of IoT tools leads to the rapid transfer of data from charities to donors due to the extent and acceleration of data flow. In this regard, decisions about how to supply food, distribute and store food are made at a high speed due to the presence of IoT. Due to the importance of IoT tools, such as RFID, information sensors, customer relationship management devices and other IoT-based tools, data is collected from different levels of the food bank supply chain. As shown in Figure (2), Big Data from various sources can be collected by IoT devices and stored in databases. After collecting data and using advanced information system and optimization tools, data analysis and making the best decisions are done. The result of this leads to the reduction of the costs of the entire supply chain of the food bank and the maximum supply of food to charities. Therefore, Figure (2) shows the food bank supply chain framework based on IoT and Big Data.

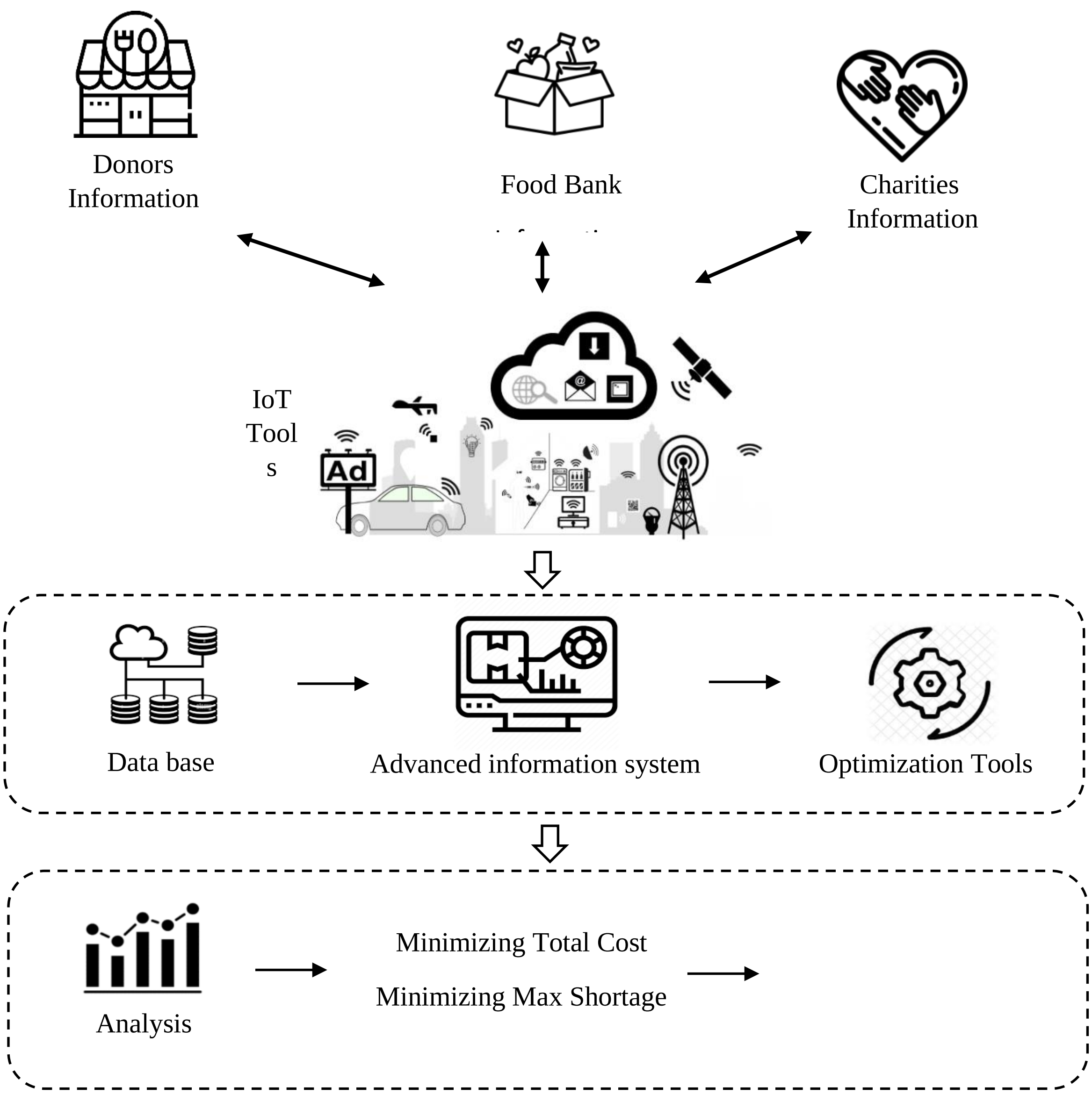

Figure 2. Food bank supply chain framework based on IoT and Big Data

By providing the framework of Figure (2), useful information from restaurants, catering, food banks, hospitals, charities, etc. can be collected in the database and take the best decisions to reduce total costs and minimize the maximum shortage (maximizing the demand estimate of charities). In order to implement the stated framework, the country of Iran has been studied and by using the IoT tool, the food demand for charitable organizations has been provided to the food banks. SWM and LP-Metrics multi-objective decision making methods have been used to analyze the big data collected using IoT tools. For this purpose, Figure (3) shows the supply chain network of the Food Bank of Iran.

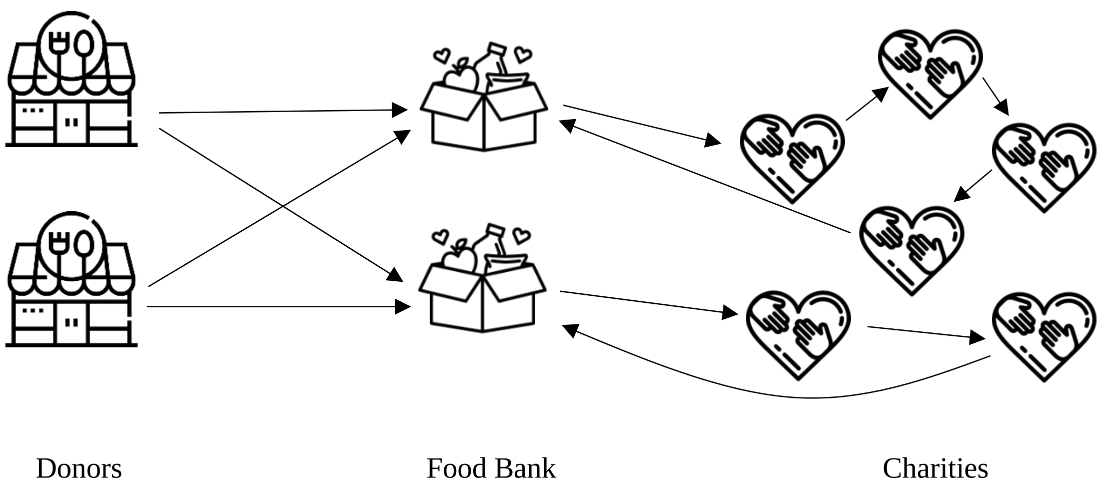

Figure 3. Food bank supply chain network

According to figure (3), the food bank network consists of donors, food bank and charity institutions. The purpose of this model is to make strategic and tactical decisions such as vehicle routing for food distribution, allocation of food flow between donors and food banks, and determining the amount of food stock. In this network, food banks collect food from donors and package them for distribution to charities. According to the demand of each charitable institution, food banks distribute food in the form of vehicle routing. Taking strategic and tactical decisions in this case is aimed at minimizing the costs of the entire network and minimizing the maximum shortage.

According to the assumptions of the problem, the symbols used in the mathematical model are presented as follows:

Sets

I	The set of food donors $i \in \{1,2,\dots,I\}$
L	The set of food banks $l \in \{1,2,\dots,L\}$
C	The set of charitable institutions $c, c\text{^}' \in \{1,2,\dots,C\}$
V	Set of vehicles $v \in \{1,2,\dots,V\}$
T	The set of time periods $t \in \{1,2,\dots,T\}$
P	Food set $p \in \{1,2,\dots,P\}$

Parameters

ξ	Shipping cost per kilometer
o_{lp}	Operational cost of packing and distributing food $p \in P$ in food bank $l \in L$
s_{lp}	Operational cost of food distribution $p \in P$ in food bank $l \in L$
h_{pt}	The cost of keeping food item $p \in P$ in the food bank in the time period $t \in T$
d_{cpt}	The maximum demand of charity $c \in C$ for food $p \in P$ in the time period $t \in T$
ψ_{lp}	Maximum distribution capacity of food bank $l \in L$ of food $p \in P$
c_{ipt}	Amount of supply of food item $p \in P$ by donor $i \in I$ in time period $t \in T$
$di_{nn'}$	The distance between node $n \in \{L \cup I \cup C\}$ and node $n^\wedge{}' \in \{L \cup I \cup C\}$
γ_{vp}	Maximum vehicle capacity $v \in V$ of food $p \in P$

Decision making variables

W_{lpt}	Number of food item $p \in P$ distributed from food bank $l \in L$ in time period $t \in T$
O_{ilpt}	Amount of food $p \in P$ transferred from donor $i \in I$ to food bank $l \in L$ in time period $t \in T$
G_{cbt}	Percentage of food $p \in P$ fulfilled by charity $c \in C$ in time period $t \in T$
Q_{lpt}	Stock amount of food item $p \in P$ in food bank $l \in L$ at the end of time period $t \in T$
U_{cvt}	Auxiliary variable to remove sub-tour
$X_{nn'vt}$	takes the value 1, if the vehicle $v \in V$ moves from the node $n \in \{L \cup C\}$ to the node $n^\wedge{}' \in \{L \cup C\}$ in the time period $t \in T$; Otherwise, it takes the value 0.
Y_{ilvt}	takes value 1, if vehicle $v \in V$ moves from donor $i \in I$ to food bank $l \in L$ in time period $t \in T$; Otherwise, it takes the value 0.
R_{lcvt}	takes value 1, if charity c∈C is assigned to food bank $l \in L$ and vehicle $v \in V$ in time period $t \in T$; Otherwise, it takes the value 0.

Based on the defined symbols, the mathematical model of the food bank supply chain network is as follows:

$$Min\ OBF_1 = \sum_{n\in\{C\cup L\}} \sum_{n'\in\{C\cup L\}} \sum_{v\in V} \sum_{t\in T} \xi di_{nn'} X_{nn'vt} + \sum_{i\in I} \sum_{l\in L} \sum_{v\in V} \sum_{t\in T} \xi di_{il} Y_{ilvt} + \sum_{i\in I} \sum_{l\in L} \sum_{p\in P} \sum_{t\in T} s_{lp} O_{ilpt} + \sum_{l\in L} \sum_{p\in P} \sum_{t\in T} s_{lp} W_{lpt} + \sum_{l\in L} \sum_{p\in P} \sum_{t\in T} h_{pt} Q_{lpt} \quad (1)$$

$$Min\ OBF_2 = \max_{p,t,c} \sum_{l\in l} \sum_{v\in V} (1 - G_{cbt}) d_{cpt} R_{lcvt} \quad (2)$$

$s.t$:

$$\sum_{v\in V} \sum_{n\in\{L\cup C\}} X_{ncvt} = 1, \qquad \forall\ c \in C, t \in \quad (3)$$

$$\sum_{\substack{n'\in\{L\cup C\}\\ n'\neq n}} X_{n'cvt} = \sum_{\substack{n'\in\{L\cup C\}\\ n'\neq n}} X_{cn'vt}, \qquad \forall\ v \in V, c \in C, t \in T \quad (4)$$

$$\sum_{l\in L} \sum_{c\in C} X_{lcvt} \leq 1, \qquad \forall\ v \in V, t \in T \quad (5)$$

$$-R_{lcvt} + \sum_{n\in\{L\cup C\}} (X_{lnvt} + X_{ncvt}) \leq 1, \qquad \forall\ l \in L, c \in C, v \in V, t \in T \quad (6)$$

$$U_{cvt} - U_{c'vt} + |C| X_{cc'vt} \leq |C| - 1, \qquad \forall\ c, c' \in C, v \in V, t \in T \quad (7)$$

$$W_{lpt} = \sum_{c\in C} \sum_{v\in V} d_{cpt} G_{cpt} R_{lcvt}, \qquad \forall\ l \in L, p \in P, t \in T \quad (8)$$

$$\sum_{i\in I} O_{ilpt} + Q_{lp,t-1} - Q_{lpt} = W_{lpt}\,, \qquad \forall\, l \in L, p \in P, t \in T \tag{9}$$

$$\sum_{l\in L} O_{ilpt} \le c_{ipt}, \qquad \forall p \in P, v \in V, t \in T \tag{10}$$

$$\sum_{p\in P} O_{ilpt} \le \sum_{p\in P}\sum_{v\in V} \gamma_{vp} Y_{ilvt}\,, \qquad \forall i \in I, l \in L, t \in T \tag{11}$$

$$\sum_{c\in C}\sum_{l\in L} d_{cpt} G_{cpt} R_{lcvt} \le \gamma_{vp}\,, \qquad \forall p \in P, v \in V, t \in T \tag{12}$$

$$R_{lcvt}, X_{nn'vt}, Y_{ilvt} \in \{0,1\} \tag{13}$$

$$W_{lpt}, O_{ilpt}, Q_{lpt} \ge 0 \;\&\; integer \tag{14}$$

$$U_{cvt}, G_{cpt} \ge 0 \tag{15}$$

Equation (1) minimizes the costs of the entire food bank supply chain. These costs include transportation costs, distribution and packaging costs, and maintenance costs. Equation (2) minimizes the maximum shortage of distributed food. Relation (3) guarantees that each charity must be assigned to one of the vehicles. Equation (4) shows that each vehicle must leave after delivering food to a charity. Equation (5) shows that each path must be covered by at most one vehicle. Equation (6) shows that each vehicle must return to the food bank after visiting the charities. Equation (7) is the equation related to sub-tour elimination. Equation (8) shows the total amount of food distributed to charities. Equation (9) shows the amount of food stored in the food bank at the end of each time period. Equation (10) shows the maximum amount of food supply by donors. Relationships (11) and (12) show the use of vehicles in collecting and distributing food from donors and charities. Relations (13) to (15) express the type of decision making variables.

4-Decision optimization methods based on Big Data

In the previous section, the food bank supply chain problem was investigated based on different assumptions and a mathematical model was designed from it. Considering the collection of information through IoT tools and Big Data analysis with the help of optimization methods, SWM and LP-Metrics methods have been presented.

4-1-Individual optimization method

In this method, the optimal solution of each single-objective problem is an efficient solution for the multi-objective problem. In other words, the programming model is solved each time by one of the objective functions, if all the obtained solutions are equal, we will have an ideal solution.

4-2-LP-Metrics method

The LP_Metric method is one of the prominent MCDM methods in multi-objective optimization problems with inconsistent objectives. In this technique, by using the optimal values of the existing objective functions and the weights provided by DM and with the help of the following relationship, the multi-objective problem becomes a single-objective problem.

$$MinD = \left(\sum_{g=1}^{D} w_g \left(\frac{f_g^* - f_g}{f_g^*}\right)^r\right)^{1/r} \tag{16}$$

In the above relationship, f_g is the gth objective function of the problem, f_g^* is the best value of the gth objective function obtained from the individual optimization method and soft r of the model. $w_g$is also the weighted importance of the gth objective function of the problem.

4-3-SWM method

To use this method, in addition to obtaining the best value of each objective function from the individual optimization method, the worst value of each objective function is also needed. The aim of this method is to minimize the distance between the objective functions from their ideal value. The following relationship shows the mentioned method.

$$Min\ \vartheta = \varphi\vartheta_0 + (1-\varphi)\sum_{g=1}^{D} w_g\left(\frac{f_g^* - f_g}{f_g^*}\right)$$

$$s.t: \quad (17)$$

$$\vartheta_0 \leq \frac{f_g^* - f_g}{f_g^*}, \quad \forall g \in D$$

In the above relationship, φ is equal to the compensation coefficient of the objective functions and the sum of the weights of the objective functions should be equal to one.

5-Food bank supply chain analysis

5-1-Validation of food bank network model

In order to validate the model and examine the output variables of the problem, a case study has been conducted in Iran (Tehran metropolis). A case study conducted in Iran and 22 municipal districts of Tehran province with an area of about 730 square kilometers is in accordance with Figure (4). In this study, 3 different types of food including cooked meat with 243 calories and a perishable time of 2 hours, vegetables and fruits with 229 calories and a perishable time of 5-7 days, and canned food with 456 calories and a perishable time of 5 hours are considered in one week of the year. According to studies, the average amount of calories needed by the body is about 2800 calories for men and about 2200 calories for women. Donors of these items include large restaurants in the city, universities, grocery stores and residential houses. Based on the studies and according to the population of Tehran, areas 2, 6, 7, 8, 12, 14, 15, 16, 18, 19, 20 and 21 have been considered as demand areas (charity institutions) that should be taken to meet their demand. Also, all areas of Tehran city have been considered as potential points for food banks.

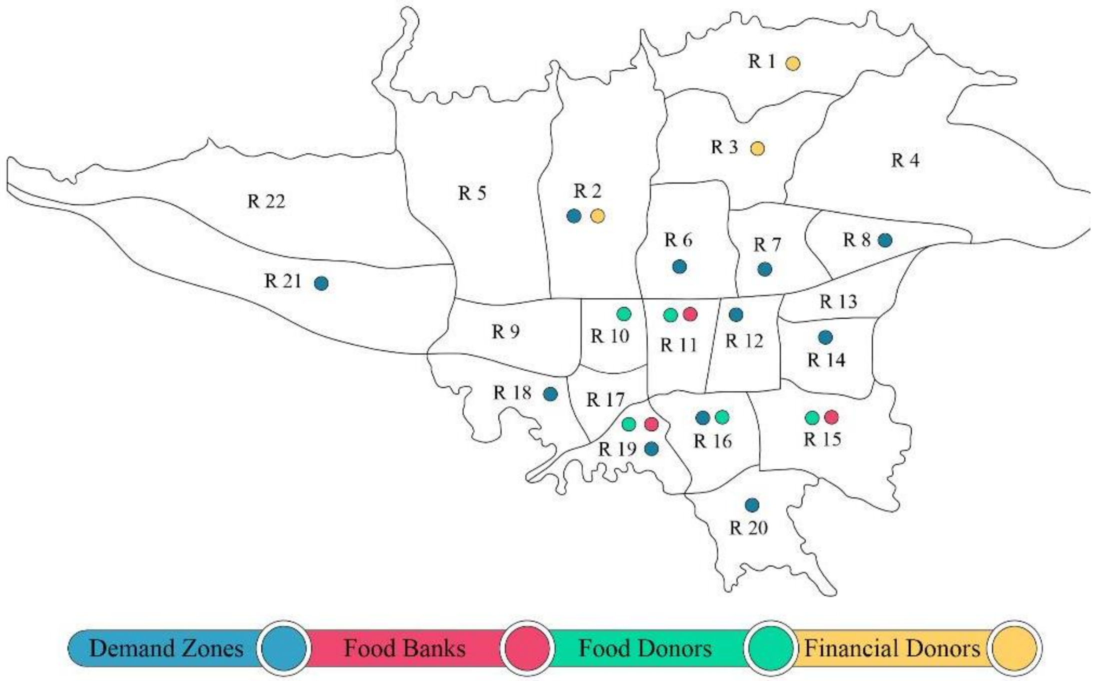

Figure 4. Scope of the case study

Estimation of demand and supply is done through IoT and Big Data tools. Food storage cost is estimated at $2 and operational costs at $1. Vehicle transportation costs between different areas of Tehran are based on the distance between areas. Also, the transport capacity of each vehicle is equal to 3000 packages. Table (1) shows the set of efficient solutions obtained from solving the case study with SWM and LP-Metrics methods.

Table 1. Set of effective solutions to the problem

SWM		LP-Metrics		Kara's Answer
OBF_2	OBF_1	OBF_2	OBF_1	
190.05	9869.54	192.03	9622.58	1
180.71	10648.57	181.54	10259.95	2
164.33	11691.67	163.13	11436.28	3
150.69	12483.37	149.08	12454.12	4
138.16	12960.44	136.9	13886.34	5
124.63	14071.40	128.49	14564.67	6
110.78	15113.22	111.7	15020.86	7
100.74	16094.20	95.54	16238.68	8
85.94	16778.27	60.51	17757.95	9
65.32	17743.77	20.56	18574.2	10
13.80	18781.96	-	-	11

The results of table (1) show that with the reduction of food shortage in the food bank supply chain, the cost of transportation and maintenance in the food bank network has increased. Therefore, the objective functions of the problem are in contradiction with each other. Also, the LP-Metrics method has obtained 10 effective answers and the SWM method has obtained 11 effective answers. In this analysis, the best value of the first objective function was equal to 9532.68 and the best value of the second objective function was equal to 5.14. In figure (5), the Pareto front obtained from solving the case study and in the following, the first efficient solution of the problem according to figure (4) is examined. In this figure, the location of food and financial donors is specified and the location-routing of transportation is also specified.

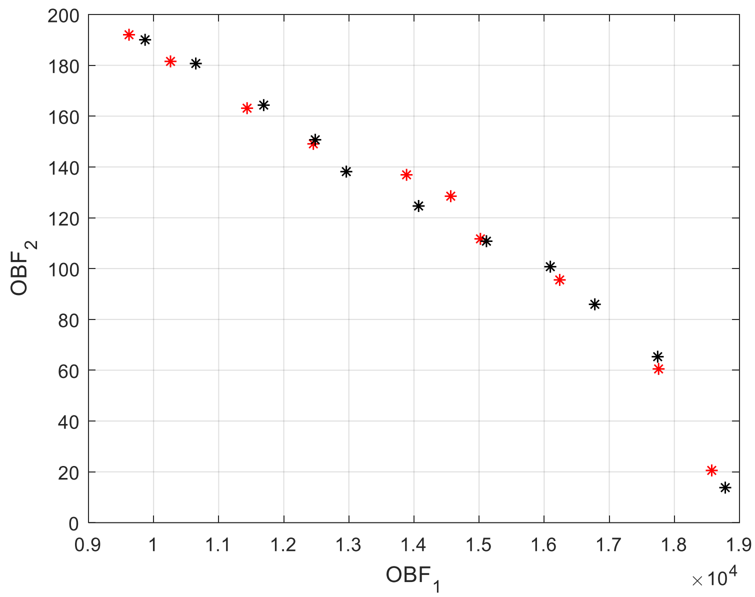

Figure 5. Comparison of the Pareto front of the case study between the two solution methods

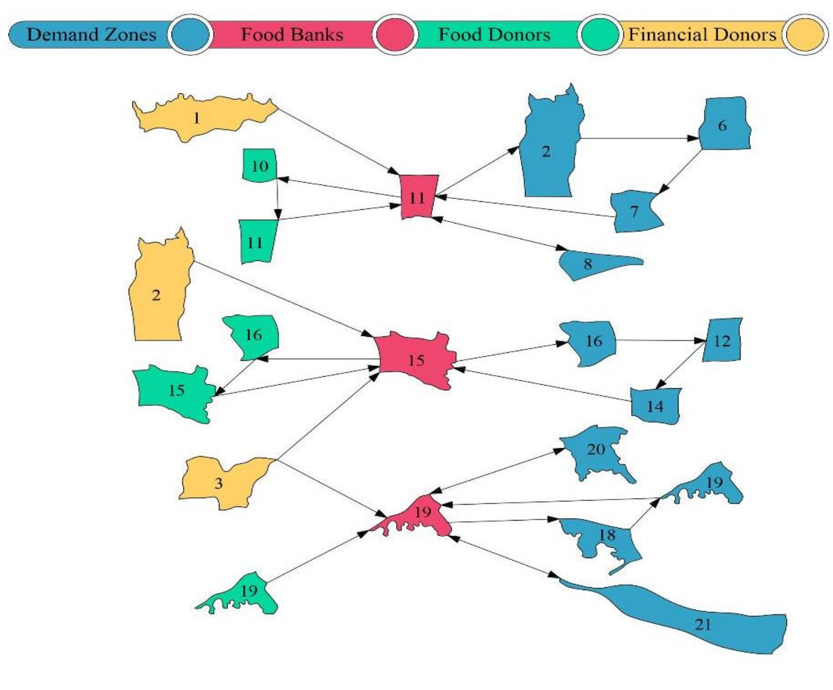

Figure 6. Real case study location and routing

The results of Figure (6) show that the number of vehicles required is 12. In this analysis, regions No. 11, 15, and 19 have been selected as food banks, and the information related to demand from regions 2, 6, 7, 8, 12, 14, 16, 18, 19, 20, and 21 has been obtained by IoT-based tools. If there are changes in the information obtained from IoT devices, the values of the objective functions of the problem will be overshadowed. In table (2), the sensitivity analysis of the mathematical model of the food bank network on the effective answer to number (10) and on the increase in demand has been discussed. In this analysis, it is assumed that the amount of demand has increased by 10-90% compared to the estimates.

Table 2. Changes in the values of the objective functions of the problem due to the increase in demand

Increase in demand	OBF_1	OBF_2	Percentage of changes OBF_1	Percentage of changes OBF_2
0	18574.20	20.56	0	0
10	18867.23	22.37	1.58	8.80
20	19035.48	24.48	2.48	19.07
30	19347.66	27.15	4.16	32.05
40	19648.27	29.33	5.78	42.66
50	20034.08	35.48	7.86	72.57
60	20648.39	38.94	11.17	89.40
70	21287.83	42.56	14.61	107.00
80	22038.49	46.84	18.65	127.82
90	22749.00	52.84	22.48	157.00

According to the sensitivity analysis performed on the demand, it can be seen that with the increase in demand, due to the increase in the number of vehicles for collecting and distributing food, transportation costs have increased. On the other hand, with the increase in demand, the amount of shortage has also increased in the network. Figure (7) shows the changes in the values of the objective functions of the problem due to the increase in demand.

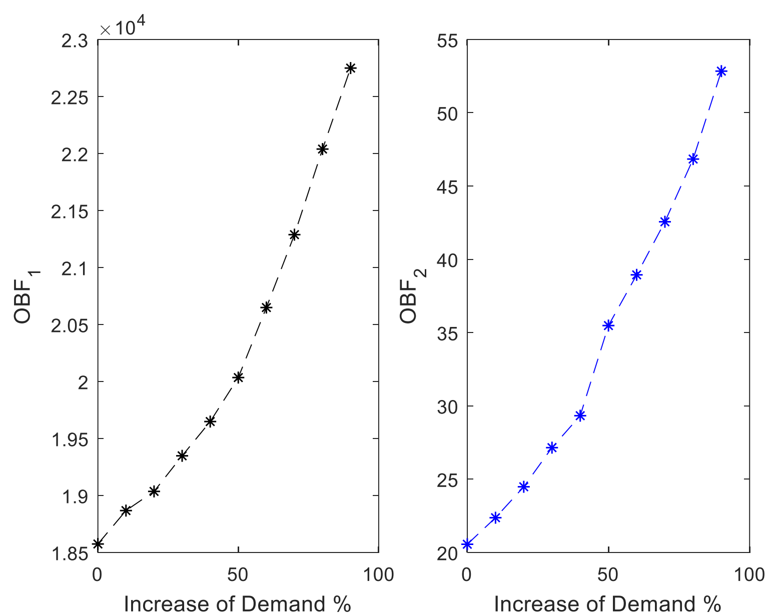

Figure 7. Variations of increasing demand on the objective functions of the problem

In the previous section, a numerical example was analyzed with LP-Metrics and SWM method for Tehran metropolis and the results showed that 10 effective answers were obtained in 125.48 seconds by

LP-Metrics and 11 effective answers were obtained in 143.55 seconds by SWM. Other comparison indicators are shown in Table (3).

Table 3. Comparison indices of efficient solutions with different solution methods

Solution method	NPF	MSI	SM	CPT
LP-Metrics	10	1571.71	0.411	125.48
SWM	11	1866.18	0.439	143.55

According to the results of table (3), it can be seen that the LP-Metrics method has the lowest space metric (SM) and CPU time (CPT) index and the SWM method has the highest number of pareto front (NPF), maximum spread index (MSI) index. In the next section, in order to check the efficiency of the solution methods, different numerical examples from the case study have been considered.

5-2-Analysis of different numerical examples on the food bank network

In this section, 15 different numerical examples of the sample problem are designed according to table (4). In this table, each of the 22 districts of Tehran are divided into several sections. Table (5) also shows the values of comparison indices in the mentioned numerical examples. Also, T-Test statistical test at 95% confidence level has been used to check the significant difference of the averages of each index among meta-initiative algorithms.

Table 4. Size of numerical examples in larger sizes

Numerical examples	$\|I\|$	$\|L\|$	$\|C\|$	$\|V\|$	$\|T\|$	$\|P\|$
1	5	6	10	10	3	4
2	6	8	15	10	3	4
3	8	12	18	10	3	4
4	10	18	25	20	4	4
5	12	20	32	20	4	5
6	15	25	40	20	4	5
7	20	30	50	30	4	5
8	25	35	62	30	6	6
9	30	40	70	30	6	6
10	35	45	80	40	6	6
11	40	50	90	40	6	6
12	50	55	100	40	8	6
13	60	60	110	50	8	7
14	70	70	120	50	12	7
15	80	75	130	50	12	8

Table 5. Effective answer indices in different numerical examples with LP metric

Numerical examples	SWM				LP-Metrics			
	NPF	MSI	SM	CPT	NPF	MSI	SM	CPT
1	17	202613.55	0.750	132.08	13	211244.99	0.732	117.61
2	22	233341.06	0.633	195.90	18	239006.08	0.659	186.45
3	29	187400.09	0.828	270.49	16	182860.68	0.822	253.32
4	23	256170.57	0.370	350.54	25	238111.61	0.370	333.96
5	20	219734.28	0.716	467.62	26	230885.38	0.899	426.62
6	22	193249.55	0.661	586.10	17	233172.54	0.995	536.51
7	18	245172.27	0.634	698.96	23	216827.18	0.937	640.02
8	20	243739.34	0.799	844.24	24	185634.01	0.662	770.17
9	20	159227.53	0.584	1010.15	27	212975.13	0.699	929.87
10	23	180678.89	0.705	1224.39	19	159322.54	0.807	1080.79
11	22	274319.95	0.779	1472.40	24	177050.36	0.757	1290.23
12	23	171542.92	0.582	1767.59	24	275867.64	0.703	1482.00
13	18	244552.74	0.614	2029.08	16	217792.58	0.835	1763.65
14	19	265184.87	0.745	2423.87	18	269553.92	0.608	2062.12
15	21	164968.45	0.634	2945.14	18	289841.32	0.652	2444.73

The results of Table (5) show that SWM has on average the highest NPF, MSI and the lowest SM compared to LP-Metrics. While LP-Metrics was more efficient than SWM only in solving the problem. This issue shows that different solution methods have been effective in obtaining different indicators. Figure (8) compares the indicators between the two solution methods.

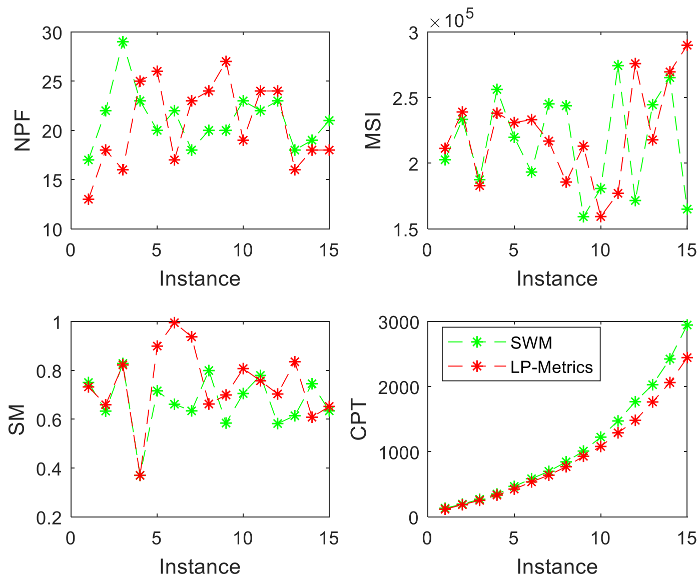

Figure 8. Comparison of indicators among different solution methods

Also, in order to ensure the obtained results, Big Data analysis of the results has been done through T-Test at the 95% confidence level. Table (6) shows the results of the t-test statistical test in examining the significant difference of the indicators at the 95% confidence level.

Table 6. The results of the t-test statistical test comparing indicators at the 95% confidence level

index	mean difference	confidence 95% interval	T-Value	P-Value
NPF	0.60	(-2.20 3.40)	0.44	0.662
MSI	6550	(-34976 21876)	0.47	0.640
SM	0.0735	(-0.0278 0.1749)	1.49	0.148
CPT	140	(-457 737)	0.48	0.634

According to the results of table (6), it can be seen that due to the P-Value being greater than 0.05, there is no significant difference in the expression of the average indicators. Due to the lack of significant difference between the averages of the comparison index between the two solution methods, the TOPSIS multi-indicator decision-making method has been used to prioritize the solution methods.

Figure (9) also shows the distance between the used indicators.

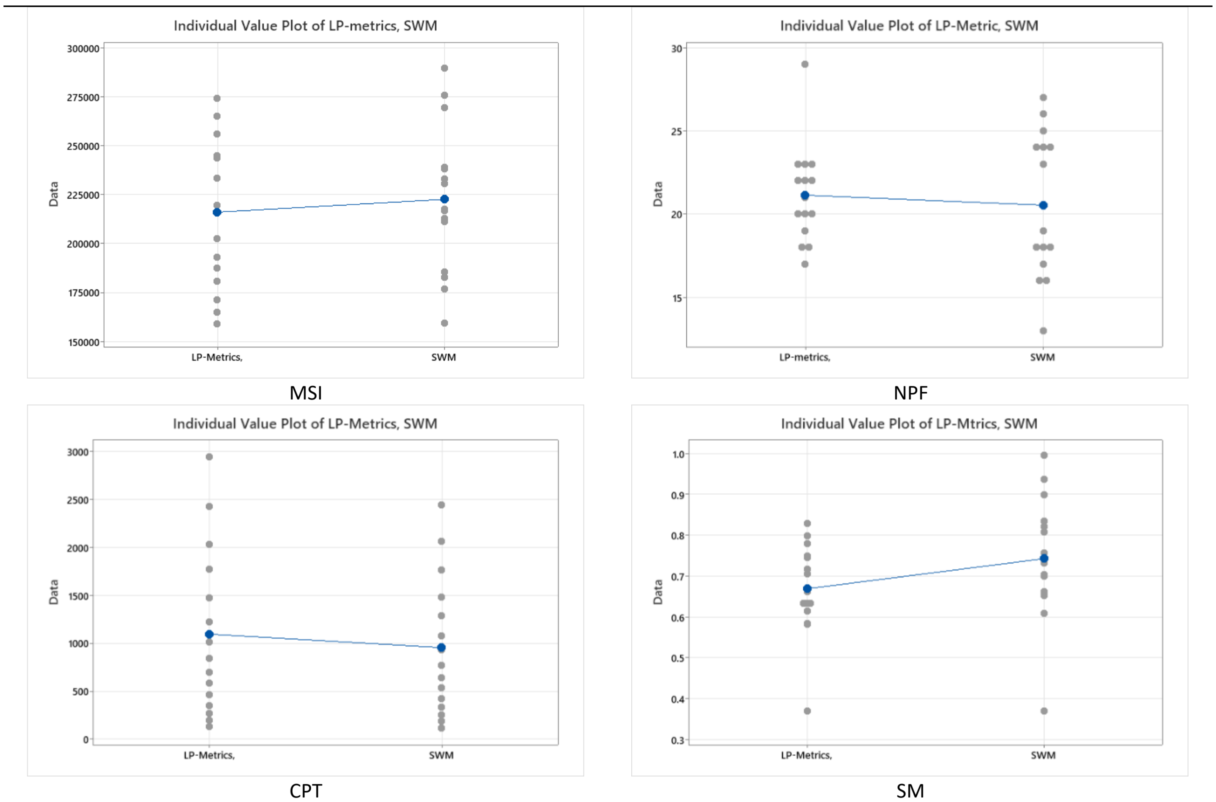

Figure 9. Diagram of distances between comparison indices

Due to the absence of significant difference between the averages of different solution methods, TOPSIS has been used to rank the solution methods. In this method, two options named LP-Metrics and SWM and 4 criteria named NPF, MSI, SM and CPT are considered. Table (7) shows the average comparison indices and the final weight of each method.

Table 7. The average indicators of the comparison of solution methods

Solution method	NPF	MSI	SM	CPT	Final weight
SWM	21.13	222676.39	0.669	1094.57	0.55
LP-Metrics	20.53	216126.40	0.742	954.53	0.45
The weight of each index	0.25	0.25	0.25	0.25	

The results of table (7) show that the final weight obtained by the SWM method is more than the LP-Metrics method, and as a result, this method can be introduced as an effective method for solving the problem.

6-Conclusion

The importance of distributing food to the needy and homeless in the real world led to the investigation of the food bank supply chain network based on IoT and Big Data based on different assumptions in this article. Therefore, in this article, a framework based on the architecture of 4 stages of IoT was presented and IoT tools were determined to collect Big Data. As a result of this, the collected data were analyzed in order to minimize the costs of the entire supply chain network and minimize the maximum shortage through LP-Metrics and SWM. The results of the analysis on the food bank network in Iran (Tehran metropolis) showed that with the improvement in the value of the second objective function, the costs of the entire network increase. The results of comparing the model with the real world also showed that if the vehicle routing problem is used to collect food instead of the allocation problem, the costs of the entire food bank network will be reduced. While in this case more vehicles are used. These analyzes help managers in choosing the type of transportation and how to collect food. So that the results of the mathematical model in a case study in Tehran metropolis showed that three areas 11, 15 and 19 were selected as food banks and 12 vehicles are needed. In this study, 10 different efficient solutions were obtained with LP-Metrics and 11 different efficient solutions were obtained with SWM. Also, if the amount of demand increases, in addition to increasing the shortage in the network, the costs related to transportation and providing food needed by charities have also increased.

According to Big Data analysis by LP-Metrics and SWM methods, 15 different numerical examples of the problem were also solved. As a result of the analysis of numerical examples, SWM obtained the highest NPF, MSI and the lowest SM compared to LP-Metrics. While LP-Metrics was more efficient than SWM only in solving the problem. Also, Big Data analysis with t-test showed that there is no significant difference between the two solution methods. By applying weight coefficients to two solution methods, an efficient SWM method was obtained for the food bank supply chain network.

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