Carbon Emission Based Optimisation Approach for the Facility Location Problem

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Abstract: In today's global competitive economy, companies should create value for customer and create value for environment to protect their competitive strengths and/or obtain competitive advantages. Creation of value depends on developing strategic approaches like determining carbon emission level to consider environmental effects. Furthermore, the financial incentives and governmental pressures on companies to reduce their emissions force companies to change and optimize their internal and external processes in order to reduce their greenhouse gas emissions.

In this paper, a carbon emission based facility location problem is discussed. A new hyrid method that aims to reduce the amount of CO_2 emission in distribution network is presented. Fuzzy C-Means and Gustafson-Kessel algorithms are used to perform clustering analyses. This is followed by the selection of appropriate facility location through the minimization of CO_2 emission levels resulting from transportation activities between the facilities and customers by using the emission based center of gravity method which is a new method developed from classical center of gravity method

Keywords: Green logistics, carbon emission, multiple facility location problems, fuzzy clustering, center of gravity.

Introduction

Parallel to the economic and technological developments, the destruction and deterioration of environmental assets along with the inability of developed societies to find solutions to the global problems such as famine, starvation, greenhouse effects etc. and the uncertainty with respect to the future of human kind (McMichael et al., 2006) has increased the awareness on environmental issues particularly in the second half of the 20th century while bringing up the concept of environmental management. In spite of the legislative reforms, changes in customer demands and inline with the international certification standards, various companies operating in different sectors have started furnishing services and manufacturing products as well as providing after-sales customer care from an environmentally conscious standpoint. In this regard, they started focusing on creating ecological assets taking up a sense of social responsibility and recently green policies have become more popular than ever.

Within the literature environmental consciousness as a general approach has become the center of attention for many disciplines, while modern logistics and supply chain management disciplines also started taking environmental issues into account. The impacts of environmental issues on several logistics decisions such as facility, warehouse and distribution centers locations or raw material sources determination, distribution types and network selection, are especially evident (Wu and Dunn, 1995).

The facility location problem has strategic significance for logistics network design (Harris et al., 2009). The term "location problem" depends on the modeling, formulation and solution of a group of problems related to locating facilities in a given space. Until today the models for facility location were used in various applications. The difference between these models emanated from the type of function, distance measurement value used, the number and the size of the sites to be established and many other variables that required decision-making (Farahani and Hekmatfar, 2009).

In general, it is possible to classify the facility location models according to the structure of the physical region as continuous, discrete and network-based models. In continuous models, the facilities can be located at any point within the multidimensional space while in discrete models; the location of the facility is selected from the pre-determined alternative location groups (Sule, 2001).

With regards to facility location problem, the type of the objective function is usually the cost minimization function. In the cost function, the total cost is expressed as the sum of all distribution costs and fixed costs. In addition to this, other objects used within the facility location problems include: institutional expenses, total annual transaction costs, average time/distance covered, minimization of variables such as the number of facilities located and maximization of facilities that are provided with services and responses.

Recently the environmental and social objectives that rely on issues such as costs related to energy and structure as well as pollution, noise, quality of life, fossil fuel crisis have all become significant for facility location problems (Farahani et al., 2010). Specifically the decisions related to the determination of the optimum number and location of services in the process of redesigning the logistic networks and these are directly related to the impacts of greenhouse effects are taken into account when realizing environmental objectives (Harris et al., 2011). However, the question of formulizing an critical environmental issue such as the carbon emission that comes up as a result of logistic activities is still among the challenges frequently discussed. The optimization methods that include carbon emission are increasing gradually in recent years.

Yurimoto and Katayama (2002) developed an algorithm for obtaining the optimal number and locations of public distribution centers in Tokyo with the aim of reducing the amount of truck CO_2 emissions while minimizing logistics costs. Ramudhin et al. (2008) introduced a mixed integer mathematical model formulation for the "Carbon-Market Sensitive - Green Supply Chain Network Design" problem and they provided decision makers to understand the trade-offs between total logistics costs and the impact of greenhouse gases reduction. Li et al. (2008) propose a bi-objective mathematical programming methodology, which aims to maximize the profits of the supply chain and to minimize the carbon emission of the supply chain while optimizing distribution center locations. They investigate the impact of crude oil price changes on location decisions. Pan et al. (2009) explored the effect of merging supply chains on reducing CO_2 emissions from transport with two possible modes, road and rail and showed that the logistical mutualisation is an efficient approach to reducing CO_2 emissions. Diabat and Simchi-Levi (2009) presented a novel optimization model for green supply chain management that integrates a mixed-integer programming model with carbon emission considerations. Govindan and Kannan (2010) developed a bi-objective model to minimize the cost function and energy consumption for a reverse logistic network design. Iakovou et al. (2010) provided a strategic decision methodological framework that identifies the optimal mixture of offshoring/nearshoring policy, while capturing quantitatively free trade and sustainability related parameters. Xiaoli et al. (2010) suggested a model of distribution centers location decision based on minimizing the carbon emissions of logistics. Based on this model, genetic algorithm was used to optimize the locations of distribution centers. Paksoy et al. (2011) proposed a multi objective mathematical model to solve the closed-loop supply chain problem for the green impacts and focused to minimize total CO_2 emissions. Wang et al. (2011) introduced a green supply chain network design model, which consider of environmental element that includes environmental level of the facility and environmental influence in the handling and transportation process. Bouzembrak et al. (2011) considered two objective functions with their multiobjective optimization model, which were total cost and total CO_2 emission in all the supply chain. Santibanez-Gonzalez et al. (2011) introduced mixed-integer 0-1 model for solving sustainable supply chain network design problem in public sector. The model involved inputs for reducing the greenhouse gas emissions produced by the transportation and the operation of the facilities and solved using a genetic algorithm. Shaw et al. (2012) proposed a model that embodied carbon footprint of the raw material and trade credit amount over the purchased item in the design phase of the sustainable supply chain. They used multi-objective goal programming to optimize total cost, total direct carbon emission, total indirect emission in a supply chain by considering different types of trucks having different emission level.

This study examines the question of facility location by applying it in the distribution network of a company in Turkey with a view to minimization of CO_2 emission levels and therefore looks into the new green logistics approach in Turkey. The remainder of the study is organized as follows: In the next section, the methods used in the study are discussed analyses. Fuzzy C-Means and Gustafson-Kessel algorithms are used to perform clustering analyses. This is followed by the selection of appropriate facility location through the minimization of CO_2 emission levels resulting from transportation activities among the facilities and customers by using the proposed emission based center of gravity method. Results and detailed discussion of the case study are presented in the third and fourth parts respectively. Finally in the last section, the conclusions are thoroughly discussed.

Materials and Method

This study considers the facility location problem as part of the supply chain management cases and takes up a different perspective to develop a new optimization method based on carbon emission.

This new method, which does not yet exist within the literature, aims to minimize the CO_2 emission levels which come out in the supply chain distribution networks by pairing the demand points with facilities. The supply chain that is considered as part of this study includes the assignment of several demand points with two or more facilities in a geographical region. During the distribution activities among these facilities and demand points, CO_2 emission emanates. The facility locations are determined in accordance with the objective of minimizing this CO_2 emission.

This method is developed as two steps and during the first step the demand points are clustered into the pre-determined number of groups depending on their geographic coordinates through the fuzzy clustering analysis methods. Following this, in the second step each group is considered as a single facility location problem within itself and the optimum facility location is selected by carbon emission based center of gravity method, which is presented here first.

Fuzzy Clustering Analysis

Organizing objects among themselves according to their similarities is called clustering analysis. These analyses form clusters of those objects that similar to each other more than the others (Jain et al., 1999).

The clusters formed within clustering analyses can be regarded as a subset of the data group. The clustering methods can be determined as crisp or fuzzy depending upon the data assigns to these subsets.

Fuzzy clustering analysis is an unsupervised method and allows the clustering of data points according to their membership degrees between 0 and 1. This provides the flexibility for data points to be expressed as belonging to more than one cluster. Thus these membership degrees would lead to better grading of the details of the data model (Döring et al., 2006).

Fuzzy C-Means (FCM) Algorithm

Fuzzy C-Means clustering algorithm is the most common partitioned clustering technique and is founded upon the minimization of an end function named as C-Means function (Bezdek and Dunn, 1975). This algorithm was first proposed by Dunn in 1973 and further developed by Bezdek in 1981 (Höppner et al., 1999).

The FCM can be seen as the fuzzified version of the k-means algorithm and is based on the minimization of an objective function called c-means functional:

$$J(X;U;V) = \sum_{i=1}^{c}\sum_{k=1}^{N}(\mu_{ik})^m \|x_k - v_i\|_A^2 \qquad (1)$$

Where A_i is a set of objects (data points) in the *i-th* cluster, v_i is the mean for that points over cluster i, $V = [v_1, v_2, \dots, v_c]$, $v_i \in R^n$ is a vector of cluster prototypes (centers), which have to be determined, $D_{ikA}^2 = \|x_k - v_i\|_A^2 = (x_k - v_i)^T A(x_k - v_i)$ is a squared inner product distance norm and the $N \times c$ matrix $U = [\mu_{ik}]$ represents the fuzzy partitions, where μ_{ik} denotes the membership degree that the ith data point belongs to the kth cluster. Its conditions are given by:

$$\mu_{ij} \in [0,1], \forall_i, k, \sum_{k=1}^{c}\mu_{ik} = 1, \forall_i, 0 < \sum_{i=1}^{N}\mu_{ik} < N, \forall_k \qquad (2)$$

FCM algorithm only can find clusters with the same shape and size because the distance norm A is not adaptive and it is often Euclidean norm (spherical clusters). The solution can be given by the lagrange multiplier method (Kenesei et.al., 2006)

Given the data set X which includes geographical $X$and Y coordinates, the number of clusters $1 < c < N$, the weighting exponent $m > 1$, the termination tolerance $\varepsilon > 0$ and the norm-inducing matrix A, the algorithm tracks the following steps (Balasko et.al., 2005).

Step 1: Compute the cluster prototypes (means):

$$V_i^{(l)} = \frac{\sum_{k=1}^{N}\left(\mu_{ik}^{(l-1)}\right)^m x_k}{\sum_{k=1}^{N}\left(\mu_{i,k}^{(l-1)}\right)^m} \qquad 1 \le i \le c \tag{3}$$

Step 2: Compute the distances:

$$D_{ikA}^2 = (x_k - v_i)^T A (x_k - v_i) \qquad 1 \le i \le c, 1 \le k \le N \tag{4}$$

Step 3: Update the partition matrix:

$$\mu_{i,k}^{(l)} = \frac{1}{\sum_{j=1}^{c}\left(D_{ikA}/d_{jk}\right)^{2/(m-1)}} \tag{5}$$

This steps will be repeated for $l = 1,2,\ldots$ until $\left\|U^{(l)} - U^{(l-1)}\right\| < \varepsilon$ where ε is the termination tolerance (Kucukdeniz et. al., 2012).

Modified Gustafson-Kessel (GK) Algorithm

Gustafson-Kessel algorithm is an extended state of the standard FCM algorithm (Kenesei et al., 2006). This algorithm was developed to detect different geometric shapes in a data set and uses Mahalanobis distance as the norm (Gustafson and Kesel, 1979; Esnaf and Küçükdeniz , 2009).

Gustafson-Kessel algorithm is based on an iterative optimization of the objective function of the c-means type (Babuska et al., 2002):

$$J(X; U, V, \{A_i\}) = \sum_{i=1}^{c}\sum_{k=1}^{N}(\mu_{ik})^m D_{ikA_i}^2 \tag{6}$$

In equation (6), $U = [\mu_{ik}] \in [0,1]^{c\times N}$ is the fuzzy partition matrix of the data $X \in R^{n\times N}$, V=[v_1, v_2 ,….., v_c], $v_i \in R^n$ is the cluster prototypes (means) vector and $m \in [1,\infty)$ is the parameter which determines the fuzziness of the resulting clusters. The distance norm D_{ikA_i} can take into account different geometric shapes in one data set and be calculated as follows:

$$D_{ikA}^2 = \|x_k - v_i\|_A^2 = (x_k - v_i)^T A (x_k - v_i) \tag{7}$$

The size of each cluster is defined for the local Ai norm matrix that is used in the formula (6) as one of the optimization variables. This allows the distance norm to adapt to the local topological structure of the data. The minimization of the GK objective functional is achieved by using the alternating optimization method that is suggested by Gustafson Kessel (1979) as based on GK algorithm (Babuska et al., 2002).

In this clustering algorithm, data samples are small or data in a cluster are linearly related to each other, covariance matrix may become singular. To solve this problem in a simple and effective way, Babuska et al. (2002) modified the GK algorithm, as given in the following details:

For the given X data set, $c, m, \varepsilon, \rho_i$ standart parameters, β threshold numbers of conditions and γ weight parameter is chosen. Initial values of partition matrix are determined and covariance matrix F_0 is calculated for all data set.

Repeat for $l = 1,2, \ldots$

Step 1: Compute cluster prototypes (means):

$$V_i = \frac{\sum_{k=1}^{N}\left(\mu_{ik}^{(l-1)}\right)^m x_k}{\sum_{k=1}^{N}\left(\mu_{i,k}^{(l-1)}\right)^m} \qquad 1 \le i \le c \tag{8}$$

Step 2: Compute the cluster covariance matrices:

$$F_i^{(l)} = \frac{\sum_{k=1}^{N}\left(\mu_{ik}^{(l-1)}\right)^m \left(x_k - v_i^{(l)}\right)\left(x_k - v_i^{(l)}\right)^T}{\sum_{k=1}^{N}\left(\mu_{ik}^{(l-1)}\right)^m} \qquad 1 \le i \le c \tag{9}$$

Add a scaled identity matrix:

$$F_i = (1-\gamma)F_i + \gamma(F_0)^{1/n} I \tag{10}$$

Extract eigenvalue λ_{ij} and Φ_{ij} from F_i
Find $\lambda_{i\,max} = maks_j \lambda_{ij}$ and set
$\lambda_{ij} = \lambda_{i\,max}/\beta \quad \forall j$ for which $\lambda_{i\,max}/\lambda_{ij} > \beta$

Reconstruct F_i by

$$F_i = [\Phi_{i1} \ldots \Phi_{in}]\, diag(\lambda_{i1}, \ldots, \lambda_{in})[\Phi_{i1} \ldots \Phi_{in}]^{-1} \tag{11}$$

Step 3: Compute the distances:

$$D_{ikA_i}^2 = \left(x_k - v_i^{(l)}\right)^T \left[\left(\rho_i det(F_i)\right)^{1/n} F_i^{-1}\right]\left(x_k - v_i^{(l)}\right) \tag{12}$$

$$1 \le i \le c \;, 1 \le k \le N$$

Step 4: Update the partition matrix:
For $1 \le k \le N$

If $D_{ikA_i} > 0$ for $1 \le i \le c$,

$$\mu_{i,k}^{(l)} = \frac{1}{\sum_{j=1}^{n}\left(D_{ikA_i}/D_{jkA_j}\right)^{2/(m-1)}} \tag{13}$$

Otherwise
$\mu_{i,k}^{(l)} = 0$ if $D_{ikA_i} > 0$ and $\mu_{i,k}^{(l)} \in [0,1]$

With $\sum_{i=1}^{K} \mu_{i,k}^{(l)} = 1$ otherwise.
Run on until $\left\|U^{(l)} - U^{(l-1)}\right\| < \varepsilon$ (Babuska et al., 2002)

The Center-of-Gravity Method

The center of gravity (COG) method tries to find the optimal solution for existing transportation facilities in a region, which gives the shortest paths. In the stage of finding this solution, significant activity areas are formulated. The aim of COG is to minimize the transportation costs either between customers and plants or between suppliers of raw materials and plants. The objective function and the basic parameters of the method are shown in equation (14) (Ballou, 1999):

$$MinTC = \sum_i V_i R_i d_i \tag{14}$$

TC : Total cost (monetary unit)
i : demand (customer) or raw material (supplier) index
V_i : quantity or demand of goods at point i (tons)
d_i : distance of plant to demand point i (km)
R_i : Transportation cost to point i (monetary unit/km)

At the first stage of this method, gravity centers of each cluster are calculated by the following formulas;

$$\overline{X} = \frac{\sum_i V_i R_i X_i}{\sum_i V_i R_i} \qquad \overline{Y} = \frac{\sum_i V_i R_i Y_i}{\sum_i V_i R_i} \tag{15}$$

Then again, d_i is recalculated with these values of the center of gravity.

$$d_i = \sqrt{\left(X_i - \overline{X}\right)^2 + \left(Y_i - \overline{Y}\right)^2} \tag{16}$$

For the new $\overline{X}$ and $\overline{Y}$ coordinates, value of d_i is put in place in the following equation.

$$\overline{X} = \frac{\sum_i V_i R_i X_i / d_i}{\sum_i V_i R_i / d_i} \qquad \overline{Y} = \frac{\sum_i V_i R_i Y_i / d_i}{\sum_i V_i R_i / d_i} \tag{17}$$

According to the latest coordinates, d_i is recalculated and iterations are continued until the difference between last two values of $\overline{X}$ and $\overline{Y}$ coordinates are lower than a specific threshold value.

Emission Based Center-of-Gravity Method

In this study, a new center of gravity method was developed by utilizing the center of gravity method that minimizes CO_2 emission instead of transportation costs. The aim of developed emission based center of gravity method is to locate facilities so that to minimize amounts of CO_2 emission that is the result of product transportation activities between production centers to demand points. Thus the environmental disadvantages can be reduced. Parameters and the objective function of this new method are shown in equation (18):

$$MinE = \sum_{\forall i \in C} d_i \times S_i \times ef_i \tag{18}$$

E : Amount of emission (kg CO_2)
i : demand (customer) or raw material (supplier) index
C : cluster index
S_i : number of transports to demand point i
d_i : distance of plant to demand point i (km)
ef_i : Emission factor (kg CO_2/km)

As is evident from Equation (18), under a fixed emission-factor the amount of CO_2 emissions is proportional to traveled distance and the number of transportations. The emission factor used in the equation is determined according to the type of vehicle. Due to the emission factor will vary according to the structure of the supply chain, when there is more than one type of transportation at the same time, this method can be used.

At the first stage of the emission-based center of gravity method, the center of each cluster is calculated in the following equation (19) by the emission factor and the number of transportation, which is demand connected variable:

$$\overline{X} = \frac{\sum_i S_i ef_i X_i}{\sum_i S_i ef_i} \qquad \overline{Y} = \frac{\sum_i S_i ef_i Y_i}{\sum_i S_i\, ef_i} \tag{19}$$

Then, the distance value is calculated with Euclidean distance formula as shown in equation (20).

$$d_i = \sqrt{\left(X_i - \overline{X}\right)^2 + \left(Y_i - \overline{Y}\right)^2} \tag{20}$$

After the value of d_i has been calculated, the value is put in place in equation (21) for new $\overline{X}$ and $\overline{Y}$ coordinates.

$$\overline{X} = \frac{\sum_i S_i ef_i X_i / d_i}{\sum_i S_i\, ef_i / d_i} \qquad \overline{Y} = \frac{\sum_i S_i ef_i Y_i / d_i}{\sum_i S_i ef_i / d_i} \tag{21}$$

According to the latest coordinates, d_i recalculated and iterations are continued until the difference between last two values of $\overline{X}$ and $\overline{Y}$ coordinates are lower than a predetermined threshold value.

The emission factor is a standardized value determined according to road conditions, traffic density and vehicle type (motor structure, ignition energy, vehicle age). Emission factor used in this study and other emission factors depending on distance of different vehicles (in kilometers) used in road transport shown in Table 1 (WRI-WBCSD GHG Protocol_Mobile Combustion CO_2 Emissions Calculation Tool. January 2003. Version 1.2).

Table 1: Emission factor varies according to vehicle class, size and the type of fuel used.

Vehicle type	**Fuel consumption**	**Activity Unit**	**Emission factor (kg CO_2 /km)**
Hybrid auto 56 mpg	4,2l/100km	vehicle kilometers	0,1001
Small gas auto 29 mpg	8,1 l/100km	vehicle kilometers	0,1932
Medium gas auto 23 mpg	10,2 l/100km	vehicle kilometers	0,2436
Large gas auto 19 mpg	12,4 l/100km	vehicle kilometers	0,2949
LPG automobile		vehicle kilometers	0,1780
Diesel auto 24 mpg	9,8 l/100km	vehicle kilometers	0,2691
Gas light truck 14 mpg	16,8 l/100km	vehicle kilometers	0,4002
Gas heavy truck 6 mpg	39,2 l/100km	vehicle kilometers	0,9338
Diesel light truck 15 mpg	15,7 l/100km	vehicle kilometers	0,4305
Diesel heavy truck 7 mpg	33,6 l/100km	vehicle kilometers	0,9226
Light motorcycle 60 mpg	3,9 l/100km	vehicle kilometers	0,0934

*mpg: Miles per galloon (the values are determined by EPA_US)

Results

In this study, the data of Esnaf and Küçükdeniz (2009) are used. Esnaf and Küçükdeniz (2009) aimed to determine optimal facility locations and identify customers that will be assigned to the facilities for an asphalt company by minimizing transportation costs. They considered shipments of suppliers-to-facilities and facilities-to-customers while calculating transportation costs. They used the amount of demands and the coordinates of the demand points appeared both the European and Asian sides of Istanbul. In this study, only the data of 51 demand points (the coordinates of demand points and amounts of demand) on the European side are considered to minimize the amount of CO_2 emissions for the uncapacitated facility location problem. In application, three different numbers of clusters were tested. Moreover two different types of vehicles, which are diesel light truck and diesel heavy truck, were assigned randomly to these demand points.

In the first step, demand points in European side are clustered into 2, 3, and 4 clusters according to their geographic locations by using MATLAB 6.5 Fuzzy Toolbox (Balasko et al., 2005) for FCM and GK fuzzy clustering algorithms which are developed in. These clusters centers have been accepted as the initial locations of facilities for the following step. In the second step, the facility locations are recalculated using the proposed emission-based center of gravity method in order to minimize the amount of CO_2 emissions between demand points and facilities.

In the case study, the vehicles, which transport between customers and facilities, are diesel heavy truck with a capacity of 20 tons and diesel light truck with a capacity of 12 tons. Furthermore, the emission factors are taken as 0.9226 kg CO_2 / km for diesel heavy truck and 0.4305 kg CO_2 / km for diesel light truck. According to the five different random number set that assign trucks to demand points, *X*, *Y* coordinates for the facilities that are found with the emission-based center of gravity hybrid methods with FCM and GK clustering algorithms are shown in Table 2.

The amount of CO_2 emissions for the different methods, are shown in the Table 3:

The average amount of CO_2 emissions for the different methods, are shown in the Table 4:

Table 3: The amount of CO_2 emissions as a result of locating facilities directly to the cluster centers that are calculated by center of gravity or emission based center of gravity hybrid methods with FCM and GK algorithms

Number of clusters	Total amount of CO_2 emission (ton CO_2)				
	Random number set	**FCM-COG**	**FCM-EBCOG hybrid method**	**GK-COG**	**GK-EBCOG hybrid method**
2	1	818.061	810.316	1166.549	1164.958
	2	824.107	816.928	1179.072	1177.381
	3	820.327	812.357	1155.313	1153.357
	4	816.694	810.147	1174.668	1173.864
	5	824.681	818.751	1169.606	1169.401
3	1	718.227	713.524	748.215	741.099
	2	720.634	716.328	746.233	738.520
	3	701.761	699.353	750.016	741.643
	4	715.357	714.087	744.339	738.071
	5	723.339	722.753	746.916	740.309
4	1	624.890	618.598	747.590	743.566
	2	629.001	622.978	746.557	742.231
	3	612.144	605.693	744.638	742.138
	4	623.409	617.927	755.726	754.527
	5	626.554	621.794	759.967	759.295

Table 4: The average amount of CO_2 emissions as a result of locating facilities directly to the cluster centers that are calculated by center of gravity or emission based center of gravity hybrid methods with FCM and GK algorithms

Number of clusters	FCM-COG	FCM-EBCOG hybrid method	GK-COG	GK-EBCOG hybrid method
2	820.774	813.700	1169.042	1167.792
3	715.864	713.209	747.144	739.928
4	623.200	617.398	750.896	748.351

Table 2: Calculated *X* and *Y* coordinates of the cluster centers (facility locations)

Number of clusters	Random number set	(*X, Y*) coordinates found by FCM-EBCOG hybrid method		(*X, Y*) coordinates found by GK-EBCOG hybrid method	
		X	Y	X	Y
2	1	70.371	22.095	74.640	28.715
		36.604	34.504	62.430	21.418
	2	70.397	21.921	74.109	28.685
		36.656	34.575	62.649	21.003
	3	69.576	21.825	74.804	28.549
		36.882	34.755	61.341	21.170
	4	69.410	21.727	73.714	28.638
		36.882	34.755	62.753	21.325
	5	69.633	21.911	74.244	28.664
		36.882	34.755	62.195	21.365
3	1	73.159	22.114	70.223	21.229
		20.636	26.599	65.788	37.556
		49.807	25.164	36.882	34.755
	2	73.152	21.739	70.556	20.879
		20.636	26.599	65.736	37.728
		50.304	25.260	36.882	34.755
	3	73.051	22.019	69.662	21.434
		20.636	26.599	65.447	38.098
		51.322	24.203	36.882	34.755
	4	72.490	21.809	69.534	21.552
		20.636	26.599	65.785	37.535
		51.395	24.177	36.882	34.755
	5	72.866	22.250	69.353	21.702
		20.636	26.599	65.785	37.535
		51.615	24.366	36.882	34.755
4	1	74.366	21.962	61.311	37.491
		3.131	43.170	3.131	43.170
		58.431	22.730	73.250	21.744
		36.882	34.755	41.040	27.263
	2	73.977	21.439	61.209	37.896
		3.433	37.630	3.433	37.630
		57.803	22.775	73.223	21.355
		36.882	34.755	41.033	27.290
	3	74.341	21.846	60.903	38.506
		4.320	33.796	4.320	33.796

	57.475	22.615	73.155	21.642
	36.882	34.755	43.242	25.410
4	73.545	21.324	61.258	38.325
	3.685	35.069	3.685	35.069
	58.479	22.442	72.639	21.393
	36.882	34.755	43.290	25.358
5	74.206	21.945	61.307	37.659
	3.433	37.630	3.433	37.630
	58.639	22.575	73.021	21.860
	36.882	34.755	42.712	26.050

Conclusion

In this study, a new center of gravity method, which aims to minimize the amount of CO_2 emission with green supply chain approach, is developed. The new method is studied in sustainable supply chain management and applied to facility location problem. The method that is called as emission based center of gravity method states facility locations by minimizing the amount of CO_2 emission, which is the result of transportation between the demand points and facilities.

The proposed FCM-EBCOG hybrid method is benchmarked against FCM-COG, GK-COG and GK-EBCOG hybrid methods in five different sets. According to average of these results, FCM-EBCOG method outperforms all other methods in all sets of clusters.

FCM-EBCOG hybrid method gives 0.87%, 0,37% and 0,93% better total amount of CO_2 emissions results than FCM-COG method in two, three and four-clustered solutions, respectively. Similarly GK-EBCOG hybrid method achieves 0.11% lower results in two-clustered solution, 0.97% lower results in three-clustered solution and 0.34% lower results in four-clustered solution than GK-COG method.

If sustainable development is one of the most important subjects for companies, it must be also under debate for the facility location problem. Proposed emission based method helps to close the gap in this field.

In conclusion, in supply chain management applications that sustainability gains ground, carbon emission based methods should be developed. Methods developed with this concept will facilitate to minimize environmental damage of industrial applications as seen from this study. Therefore, this provides companies to operate globally in an ever environmentally conscious world.

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