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An Environmentally Conscious Multi-Objective Weber Problem for Green Location and Distribution Planning: A Fuzzy Weighted Additive Approach

Yeşil Alan ve Dağıtım Planlaması için Çevreye Duyarlı Çok Amaçlı Bir Weber Problemi: Ağırlıklandırılmış Bulanık Toplama Yöntemi

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ABSTRACT: In this study, a multi-objective Weber (p-median) problem is treated in order to determine the location of the warehouses to be opened and the distribution plans of products. The company carries out the distribution with three types of vehicles differing in unit transportation cost, carbon emission and velocity. Three conflicting objectives are aimed to be minimized, i.e.; the demand weighted total transportation cost, the total delivery time and the total carbon. We adopted a fuzzy weighted additive approach to deal with the multi-objective optimization function, in which the weights of each individual objective function are determined by Analytic Hierarchy Process.

Keywords: Analytic Hierarchy process, fuzzy weighted additive solution approach, multi-objective optimization, P-median

JEL Classifications: C6, L9

Öz: *Bu çalışmada, açılacak depoların konumunu ve ürünlerin dağıtım planlarını belirlemek amacıyla çok amaçlı bir Weber (p-medyan) problemi ele alınmıştır. Modelde dağıtım, birim taşıma maliyeti, karbon emisyonu ve hızları farklı olan üç tip araç ile yapılmaktadır. Talep ağırlıklı toplam ulaşım maliyeti, toplam teslimat süresi ve toplam karbon emisyonu gibi birbirleriyle çelişen 3 farklı amacın aynı anda enküçüklenmesi hedeflenmiştir. Amaçların ağırlıkları Analitik Hiyerarşi Süreci ile belirlenmiş ve çok amaçlı optimizasyon modeli, ağırlıklandırılmış bulanık toplama yöntemi ile çözülmüştür.*

Anahtar Kelimeler: *Analitik hiyerarşi süreci, ağırlıklandırılmış bulanık toplama yöntemi, çok amaçlı optimizasyon, P-medyan*

1. Introduction

As the climate change-induced environmental degradation raises concerns among the governments, legislations and protective regulations put into action that force companies decrease their environmental footprint. In developed countries (such as Canada, United Kingdom, Australia, Scandinavian countries), carbon taxes (based on the idea that polluter pays) have been enacted or proposed, which means that the companies emitting more carbon than a predetermined level is charged a varying cost per ton of carbon. And, if carbon emission is taxed, companies will either use fewer fossil fuels, reducing the amount of carbon emission, or seek alternative methods in operations, manufacturing or transportation. And if this level is set high enough, it becomes a powerful monetary disincentive that in turn encourage switching to greener

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methods, simply by making it economically more rewarding to move to carbon efficient techniques. No need to mention that going green does not only end up with environmental benefits, by doing so, companies raise brand image perceived by customers.

When it comes to Turkey, carbon taxes aren't applicable yet. Turkey became a party to the Kyoto Protocol on August 26, 2009 and United Nations Framework Convention on Climate Change (UNFCC) on May 24, 2004. Turkey has not been considered responsible of emission reduction or limitation in the first period (2008-2012), second period (2012-2016) and third period (2016-2020) of the Kyoto Protocol (Ministry of Environment and Urbanization, 2011). Due to some regulations regarding special consumption tax and tax for removal of old vehicles from traffic in 2003-2004, a reduction of 4.9% in CO_2 was achieved. Still, there are several significant measures that need to be undertaken to cut the carbon emission level in Turkey.

According to the Climate Change report published by (Intergovernmental Panel on Climate Change, 2014), based on global emission from 2010, CO_2 emission level accounted for 65% of global greenhouse gases emission (GHG), and fossil fuel use is the primary source of CO_2 emission. Transportation accounted for 14% of global GHG (Intergovernmental Panel on Climate Change, 2014). This situation led the European Commission to put forward two regulatory proposals setting the mandatory CO_2 for new cars and vans in 2020. A key element of the proposal was that a target value of 95 g/km of CO_2 for 2020 is set for the new passenger vehicle fleet, and 147 g/km of CO_2 for vans, yet the European Commission has so far not done the same for trucks, which are responsible for around a quarter of road transport emissions and that share of emissions could increase by 2030, according to the Commission (Transport & Environment, 2015).

Companies intend to find the balance between organizational cost and environmental footprint, which is a challenging practice, as these objectives are usually conflicting. In this case, from a practical point of view, managers are willing to find a good solution to both achieve economic and environmental goals.

Our motivation is to propose a fuzzy weighted solution approach for the companies in the supply chain (SC) willing to optimize multi-objective optimization problem. The remainder of the paper is as follows: Section 2 includes a brief review on studies dealing with green supply chain and fuzzy weighted solution approach. Section 3 describes the problem definition and formulation. Section 4 explains fuzzy weighted solution approach used to solve multi-objective optimization problems. Finally, in Section 5, the approach is illustrated by a case problem. Conclusions and future directions appear the next section.

2. Related Works

According to Bilir et al. (2017), 24% of studies in the supply chain literature from 2009 to 2014 includes multi-objective functions, and they are getting even popular among the researchers. Soleimani et al. (2017) considered a multi-objective closed loop supply chain in which the maximization of overall profit and meeting customer demand for new and recycled products and the minimization of missed working days due to occupational hazards and accidents. For the solution, they implemented ϵ-constraint method. Banasik et al. (2017) proposed bi-industrial mushroom supply chain to quantify trade-offs between economic and environmental goals. Economic goals involve total costs associated with production and transportation of substrate, while the environmental goals are to minimize total environmental impact associated with production and transportation of substrate. For the solution approach, they also implemented ϵ-constraint method as it is a common way to deal with multi-objective optimization. Mohammed and Wang (2017) proposed a multi-objective green meat supply chain in which the total cost of transportation and implementation, the amount of CO_2 emissions in transportation and the distribution time of products from farms to abattoirs and from abattoirs to retailers are minimized and the average delivery rate in satisfying product quantity are maximized. To optimize the four objectives simultaneously, three solution methods were investigated and used; which are the LP-metrics method, the ϵ-constraint method and the goal programming method. Sadeghi Rad and Nahavandi (2018) proposed a multi-objective green supply chain that involves the minimization of economic cost and environmental emissions and maximization of customer satisfaction. They utilized $L_p - metrics$ method to solve the multi-objective programming model. Fahimnia et al. (2015) proposed mixed-integer nonlinear mathematical model for a supply chain model dealing with tradeoff between cost and environmental degradation including carbon emissions, energy consumption and waste generation. The model also included multiple transport lot sizing and flexible holding capacity of warehouses. There are multiple products produced in manufacturing plants using machine centers with different characteristics (outdated machines are cheaper, but less carbon efficient), transported to customers through warehouses via different type of trucks including small, medium and large trucks. The objective in the proposed model was to determine the tactical planning decisions, including production and distribution allocation strategies for the planning horizon, in a way to minimize the overall cost while reducing the environmental footprint. The multiple objective function of the proposed mathematical model are converted into one weighted-sum objective function by expressing the emission, energy and waste values in equivalent dollar amount. Chan et al. (2016) developed models for three echelon SC distribution problem considering multiple-time periods, multi-products and uncertain demands. The distribution is carried out by multiple types of trucks differing in hiring cost, mileage, size and velocity. The two objectives were the cost and responsiveness of the supply chain. The distribution problem is solved using the non-dominated sorting genetic algorithm (NSGA-II). As another example to multi-objective SC optimization, Kadziński et al. (2017) investigated different solution approaches to solve multi-objective green supply chain problems. The three objectives were costs, CO_2, which is one of the Green House Gases and fine coal dust, and the solution approaches were weighted sum method in which the multiple objectives are transformed into a single one through a convex combination, epsilon constraint method, and two evolutionary algorithms, namely NSGA-II and Strength Pareto Evolutionary Algorithm 2 (SPEA2). These algorithms are based on the notion of Pareto dominance which is used for identifying the solutions that will breed and those to be replaced. Talaei et al. (2016) proposed a mixed integer linear programming model for a facility location/allocation, multi-product closed-loop green supply chain network consisting of manufacturing/remanufacturing and collection/inspection centers as well as disposal center and markets, minimizing the network total costs and also the amount of carbon emitted out by the network. Fuzzy programming approach is implemented to cope with the uncertainties of the variable costs and demand rate. Also, they used ε-constraint approach to solve the bi-objective model.

As to the solution approach review, Fuzzy weighted solution approach developed by Tiwari et al. (1987) has been mostly used for multi-objective supplier selection problem (Amid et al., 2009; Arikan, 2013; Kavitha, 2013; Mehlawat & Kumar, 2017; Pan et al., 2015; Seifbarghy et al., 2011; Shaw et al., 2012). Shaw et al. (2012) used two approaches developed by Zimmermann (1978) and Tiwari et al. (1987). Supplier selection problems involve selection of the best supplier with regard to some criteria, such as price, quality, customer service, or delivery. The objectives include, for example, the minimization of costs, maximization of quality and maximization of on-time delivery etc.

To the best of our knowledge, it is the first time in literature that a multi-objective p-median problem has been dealt with fuzzy weighted additive method. In this regard, this study sets an example for practitioners willing to find the best compromise solution which satisfies different goals, such as economic and environmental using fuzzy weighted additive method. It is intended to give an example for practitioners as this method allows network managers to assign different weights to each objective functions which it is very common in real world applications.

3. Problem Definition and Formulation

In this study, a multi-objective P-median problem is developed in order to determine the location of the warehouses to be opened and the distribution plans of products from the potential warehouses to the final customers, in an environmentally conscious manner. The company carries out the distribution with three types of vehicles. The first type is a vehicle with a small size (van) and a high unit transportation cost, but with a low carbon emission and fast delivery time (t_1). The second type of vehicle (truck) is a slightly larger vehicle with lower transportation cost per unit, but it is an option with slower delivery time (t_2) that emits more carbon compared to van. The third type of vehicle (heavy truck) is a vehicle with the lowest transportation cost per unit which has the slowest delivery time (t_3) and it releases the highest amount of carbon emissions among the vehicle types.

The following assumptions are considered for mathematical modelling:

- Demand of customers is deterministic and known in advance.
- Unit transportation cost, velocity and emission rate are available for van, truck and heavy truck.
- Potential location of warehouses are known in advance.

Three conflicting objectives are considered to be minimized, i.e.; the demand weighted total transportation cost (classic Weber objective function), the total delivery time (t_1+t_2+t_3) and the total carbon emissions emitted in the network. As the different objective functions come with different units in this case, we adopted a fuzzy weighted additive approach, proposed by Tiwari et al. (1987), to reduce multi-objective optimization function into a simple weighted additive model through achievement functions and the weights of each individual objective function are determined by Analytic Hierarchy Process (AHP).

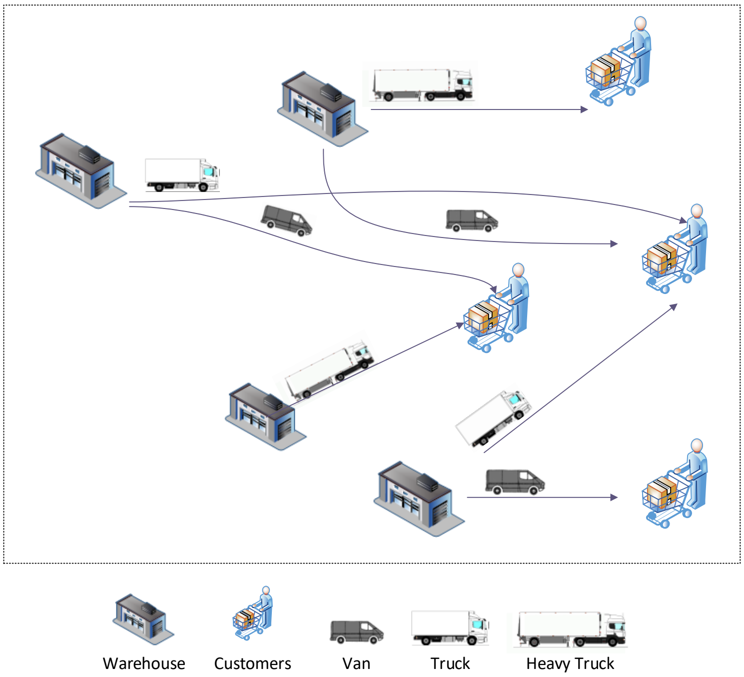

Figure 1. Supply Chain Network Scheme

3.1. Sets and decision variables

The sets and indices used in this model are as follows:

W set of warehouses, indexed by w
K set of vehicle types, indexed by k
I set of point of sale, indexed by i

Binary decision variables are as follows:

$$X_{wki} = \begin{cases} 1, \text{if point of sale } i \text{ is served by vehicle type } k \text{ from warehouse } w \\ 0, \text{otherwise} \end{cases}$$

Another binary decision variable is needed to determine if warehouses are opened or not.

$$Y_w = \begin{cases} 1, & \text{If warehouse } w \text{ is opened} \\ 0, & \text{otherwise} \end{cases}$$

3.2. Parameters

d_{wi} The distance between point of sale i and warehouse w
wd_i The weight of demand for point of sale i
c_k The unit transportation cost of vehicle type k
v_k The velocity of vehicle type k
CO_k Average carbon emission of vehicle type k
t_{wki} Duration of transportation from warehouse w to the point of sale i with vehicle type k
P Maximum predetermined number of warehouse that can be opened

ρ_1 Coefficient for Cost function
ρ_2 Coefficient for Total duration of transport
ρ_3 Coefficient for Total carbon emission

3.3. Objective Functions

Three conflicting objectives are considered to be minimized. The first objective function (Z_1) is the demand weighted total transportation cost (classic Weber objective function). The second objective function (Z_2) specifies the total duration of transport in the network, and the third objective function (Z_3) specifies the total carbon emissions.

$$Z_1 = \sum_{\mathrm{w,i,k}} wd_i * d_{wi} * c_k * x_{wki} \tag{1}$$

$$Z_2 = \sum_{\mathrm{w,i,k}} t_{wki} \tag{2}$$

$$Z_3 = \sum_{\mathrm{w,i,k}} x_{wki} * CO_k \tag{3}$$

$$Z = \rho_1 Z_1 + \rho_2 Z_2 + \rho_3 Z_3 \tag{4}$$

s.t.

$$\sum_{w,k} x_{wki} = 1\,, \;\; i \in I \tag{5}$$

$$x_{wki} \le y_w; \quad (\mathrm{i} \in \mathrm{I}), (\mathrm{w} \in \mathrm{W}), (\mathrm{k} \in \mathrm{K}) \tag{6}$$

$$\sum_{w} y_w = P \tag{7}$$

$$60 * x_{wki} * d_{wi} \div v_k = t_{wki}; \quad (\mathrm{i} \in \mathrm{I}), (\mathrm{w} \in \mathrm{W}), (\mathrm{k} \in \mathrm{K}) \tag{8}$$

$$x_{wki}, y_w \in \{0,1\}; \quad (\mathrm{i} \in \mathrm{I}), (\mathrm{w} \in \mathrm{W}), (\mathrm{k} \in \mathrm{K}) \tag{9}$$

Eq. (1), (2) and (3) calculate the demand weighted total transportation cost, total duration of transport in the network, and the total carbon emissions, respectively. Constraint (4) is the weighted sum of these objective functions. Constraint (5) ensures that each customer will be served exactly by one warehouse using one type of truck. Constraint (6) ensures the opening of a warehouse if it is used. Constraint (7) restricts the number of opened warehouse is to be equal to *P*. Constraint (8) calculates the duration of transportation from warehouse *w* to the point of sale *i* with vehicle type *k*. Constraint (9) declares the binary variables in the programming model.

4. Solution Approach: Fuzzy Weighted Additive Model

Fuzzy weighted additive approach, developed by Tiwari et al. (1987), is adopted to deal with multi-objective optimization function. By using their method, multi-objective objective function is reduced to a simple weighted additive model through achievement functions. Weights (ρ_1, ρ_2, ρ_3) are assigned by decision maker to reflect three objective functions' weights. The basic weighted additive model for a maximization problem is as follows:

$$\text{Maximize } V(\mu) = \sum_{i=1}^{m} \rho_i \mu_i \tag{10}$$

s.t.

$$\mu_i = \frac{G_i(X) - L_i}{g_i - L_i} \tag{11}$$

$$AX \leq b \tag{12}$$

$$\mu_i \leq 1 \tag{13}$$

$$X, \mu_i \geq 0, \quad i = 1,2, \dots, m \tag{14}$$

Where X is an n-vector with components $x_1, x_2, , \dots, x_n$ and $AX \leq b$ are system constraints in vector notation. A linear membership function μ_i for the i-th fuzzy goal $G_i(X) \geq g_i$, can be expressed, according to Zimmermann (1978), as follows:

$$\mu_i = \begin{Bmatrix} 1 & if\ G_i(X) \geq g_i \\ \dfrac{G_i(X) - L_i}{g_i - L_i} & if\ L_i \leq G_i(X) \leq g_i \\ 0 & if\ G_i(X) \leq L_i \end{Bmatrix} \tag{15}$$

where L_i is the lower tolerance limit for the fuzzy goal $G_i(X)$. In case of the goal $G_i(X) \leq g_i$, the membership function is defined as:

$$\mu_i = \begin{Bmatrix} 1 & if\ G_i(X) \leq g_i \\ \dfrac{U_i - G_i(X)}{U_i - g_i} & if\ g_i \leq G_i(X) \leq U_i \\ 0 & if\ G_i(X) \geq U_i \end{Bmatrix} \tag{16}$$

where U_i is the upper tolerance limit. In the objective function, the term V(μ) is called the fuzzy achievement function. This is a single objective optimization problem that can be solved by basic technique.

5. An Illustrative Example: A Case Study

The real-life data is obtained from a wholesale company based in Ankara, Turkey. The company plans to open warehouses and assign its customers (universities and high schools) to each opened warehouse, meanwhile minimizing the total transportation cost (Z_1), total duration of transport (Z_2) and total carbon emissions (Z_3) in the network. The decision maker from the company performed pairwise comparison of three objective functions using a scale from 1 to 9, which is given in

Table 1 and after that, Analytic Hierarchy Process (AHP) is used to obtain the weights for each objective function, which is a multi-objective technique introduced by Saaty (2008). It can be seen from the Table 1 that the total transportation cost (Z_1) is more important than the total duration of transport (Z_2) and slightly more important than the total carbon emissions (Z_3). And the total carbon emissions (Z_3) are slightly more important than the total duration of transport (Z_2). More information on AHP and its implementation can be found in Saaty (2008). The transportation costs per kilometer of van, truck, and heavy truck are 40, 30 and 20 Turkish Liras, respectively. The CO_2 emissions per kilometer for van, truck and heavy truck are 168.3, 200 and 250.2 grams, respectively.

Table 1. Pairwise Comparison Matrix for Three Objective Functions

Objective Functions	$\boldsymbol{Z_1}$	$\boldsymbol{Z_2}$	$\boldsymbol{Z_3}$
$\boldsymbol{Z_1}$	1	5	3
$\boldsymbol{Z_2}$	1/5	1	1/3
$\boldsymbol{Z_3}$	1/3	3	1

Through pairwise comparison matrix usage, which is a consistent evaluation, weight vector is found as $\rho = [0.633\ 0.106\ 0.259]^T$. These weights are multiplied with each membership function of fuzzy linear programming. The next step is to calculate the achievement (membership) functions, μ_i. The first step in order to calculate the achievement functions is to run the model optimizing a single objective at a time. After solving the first objective (Z_1), the lower bound optimal value of first objective function is obtained. The process is repeated for the remaining two objective functions one by one. The lower bound and upper bound for each of the objective functions are calculated using the same set of constraints. The fuzzy formulation is done using the weighted additive model proposed by Tiwari et al. (1987). Table 2 represents the upper and lower bound for each objective function.

Table 2. The upper and lower bound for each objective function.

	Values found for each objectives		
Optimized	$\boldsymbol{Z_1}$ (TL)	$\boldsymbol{Z_2}$ (min)	$\boldsymbol{Z_3}$ (gram)
$\boldsymbol{Z_1}$	1761	229.5	5000
$\boldsymbol{Z_2}$	3522	147.5	3366
$\boldsymbol{Z_3}$	7648.8	308.4	3366

The minimum and maximum values of total cost (Z_1), total duration of transport (Z_2) and total carbon emission (Z_3) are given in Table 3.

Table 3. Minimum and maximum values of each objective

Obj. Num	**Objective Function**	**μ=1**	**μ=0**
1	Z_1	1761	7649
2	Z_2	147	308
3	Z_3	3366	5000

Assuming that membership functions are linear, the achievement functions are as follows:

$$\mu_1 = \begin{cases} 1 & if\ Z_1 \le 1761 \\ \dfrac{7649 - (\sum_{\mathrm{w,i,k}} wd_i * d_{wi} * c_k * X_{wki})}{7649 - 1761} & if\ 1761 \le Z_1 \le 7649 \\ 0 & if\ Z_1 \ge 7649 \end{cases} \quad (17)$$

$$\mu_2 = \begin{cases} 1 & if\ Z_2 \le 147 \\ \dfrac{308 - (\sum_{\mathrm{w,i,k}} \frac{d_{wi} * x_{wki}}{v_k} * 60)}{308 - 147} & if\ 147 \le Z_2 \le 308 \\ 0 & if\ Z_2 \ge 308 \end{cases} \quad (18)$$

$$\mu_3 = \begin{cases} 1 & if\ Z_3 \le 3366 \\ \dfrac{5000 - (\sum_{\mathrm{w,i,k}} X_{wki} * CO_k)}{5000 - 3366} & if\ 3366 \le Z_3 \le 5000 \\ 0 & if\ Z_3 \ge 5000 \end{cases} \quad (19)$$

Using these achievement functions, the new mathematical formulation for Green P-median location and distribution problem is as follows:

$$\text{Maximize } 0.633 * \mu_1 + 0.106 * \mu_2 + 0.259 * \mu_3 \quad (20)$$

Subject to:

$$\mu_1 \le \frac{7649 - (\sum_{\mathrm{w,i,k}} wd_i * d_{wi} * c_k * X_{wki})}{5888} \quad (21)$$

$$\mu_2 \le \frac{308 - (\sum_{\mathrm{w,i,k}} \frac{d_{wi} * x_{wki}}{v_k} * 60)}{161} \quad (22)$$

$$\mu_3 \le \frac{5000 - (\sum_{\mathrm{w,i,k}} X_{wki} * CO_k)}{1634} \quad (23)$$

$$\sum_{w,k} x_{wki} = 1, \quad i \in I \quad (24)$$

$$x_{wki} \le y_w; \quad (\mathrm{i} \in \mathrm{I}), (\mathrm{w} \in \mathrm{W}), (\mathrm{k} \in \mathrm{K}) \quad (25)$$

$$\sum_{w} y_w = p \quad (26)$$

$$\frac{d_{wi} * x_{wki}}{v_k} * 60 = t_{wki}; \quad (\mathrm{i} \in \mathrm{I}), (\mathrm{w} \in \mathrm{W}), (\mathrm{k} \in \mathrm{K}) \quad (27)$$

$$x_{wki}, y_w \in \{0,1\}; \quad (\mathrm{i} \in \mathrm{I}), (\mathrm{w} \in \mathrm{W}), (\mathrm{k} \in \mathrm{K}) \quad (28)$$

The model represented in (20-28) is implemented using ILOG's CPLEX Concert Technology (version 12.6) in Visual Studio environment in C# language. The optimal solution to the fuzzy mathematical model is given in Table 4 below. Fuzzy achievement functions and the corresponding objective function values per one cycle of operations in the network are obtained.

According to the optimal solution given in Table 4, Warehouse 1, 3 and 7 should be opened in order to minimize the total transportation cost, total duration of transport and total carbon emission altogether.

Table 4. Optimal solution

X_{wki}	$X_{1,1,2}, X_{1,1,3}, X_{1,1,4}, X_{1,1,6}, X_{1,1,9}, X_{1,1,12}, X_{1,3,5}, X_{7,1,1}, X_{7,1,1}$ $X_{7,1,14}, X_{7,1,16}, X_{3,1,7}, X_{3,1,8}, X_{3,1,10}, X_{3,1,11}, X_{3,1,17}, X_{3,1,18},$ $X_{3,1,19}, X_{3,1,20} = 1$
Y_w	$Y_1 = Y_3 = Y_7 = 1$
$Min\ Z_1[1761, 7649]$	2985 Turkish Liras
$Min\ Z_2[161, 308]$	166 minutes
$Min\ Z_3[3366, 5000]$	3529 grams
μ_1	0.792
μ_2	0.881
μ_3	0.900

5.1. Scenario Analyses for larger data set

The company expects an increase in their demand and thus provided another data set including 100, 250 and 500 customers to be well prepared for the increasing demand in the upcoming season. The developed model is run and the solution for each problem is given in Table 5 (Nc represents the number of customers).

Table 5. The upper and lower bounds for each problem set

	Values found for each objectives (Nc=100)		
Optimized	Z_1 (TL)	Z_2 (min)	Z_3 (gram)
Z_1	**6934**	794	**12500**
Z_2	13869	**510**	8415
Z_3	**33360**	**1191**	**8415**
	Values found for each objectives (Nc=250)		
Z_1	**18738**	2268	**25000**
Z_2	37476	**1458**	16830
Z_3	**92296**	**3355**	**16830**
	Values found for each objectives (Nc=500)		
Z_1	**32317**	3926	**49183**
Z_2	64635	**2523**	33660
Z_3	**141218**	**5321**	**33660**

After determining the upper and lower bounds for each objective function for each problem, the fuzzy weighted additive model is run for each data set and the results are given in Table 6.

Table 6. Optimal results obtained by Fuzzy weighted additive approach

Nc=100	$\boldsymbol{Min\ Z_1[6934, 33360]}$	25527 Turkish Liras
	$Min\ Z_2[510, 1191]$	749 minutes
	$Min\ Z_3[8415, 12500]$	5263 grams
	μ_1	0.841
	μ_2	0.866
	μ_3	0.860
Nc=250	$Min\ Z_1[18738, 92296]$	77118 Turkish Liras
	$Min\ Z_2[1458, 3355]$	2028 minutes
	$Min\ Z_3[16830,25000]$	9449 grams
	μ_1	0.810
	μ_2	0.910
	μ_3	0.924
Nc=500	$Min\ Z_1[32317, 141218]$	114718 Turkish Liras
	$Min\ Z_2[2523, 5321]$	3196 minutes
	$Min\ Z_3[33660, 49183]$	20403 grams
	μ_1	0.820
	μ_2	0.842
	μ_3	0.855

The algorithm found optimal solutions in reasonable time (less than a second), even with larger data set. The managers should stick to these optimal outcomes while deciding which customers are served from which warehouses to ensure that the total cost, total delivery time and carbon emissions are minimized altogether.

6. Conclusion

As the climate change-induced environmental degradation raises concerns among the governments, legislations and protective regulations put into action that force companies decrease their environmental footprint. This led companies to simultaneously optimize their organizational cost and environmental footprint.

From a practical point of view, businesses operate under varying and often conflicting objectives, such as economic, environmental or operational goals. For example, a company can ask for reduced production cost and carbon emission per unit, increased life-span and return rate while reducing the waste treatment or discharge costs at the same time. Managers confronting this compelling and challenging issue are seeking compromised solutions balancing the distribution cost and environmental impact of their businesses. This method offers a great tool for managers and practitioners who are willing to comply with regulative legislations while reducing their total operational cost. This method allows the managers to adjust the relative importance ratios for each objective function, which also helps the managers to truly manage the network performance measures. The managers should determine their goals without paying attention to what sort of unit that each goal has, as this approach does not require all objective functions to have the same unit, unlike weighted additive approach.

In this study, a fuzzy weighted additive approach was proposed to deal with multi-objective p-median problem. Three conflicting objectives considered to be minimized were the demand weighted total transportation cost, the total delivery time and the total carbon emissions emitted in the network. The network consists of warehouses, of which the potential locations are known in advance, and customers. The decision was to determine the location of the warehouses to be opened and the distribution plans of products from the potential warehouses to the final customers using three types of vehicles. The vehicles possess different cost, velocity and carbon emission, which lead to a trade-off between the objectives. We used a fuzzy weighted additive approach, proposed by Tiwari et al. (1987), to reduce multi-objective optimization function into a simple weighted additive model through achievement functions and the weights of each individual objective function were determined by Analytic Hierarchy Process. The model was tested using real data obtained from a logistic company based in Ankara, Turkey. As a future direction, demands of customers, transportation cost carbon emission levels and velocities of vehicles may be taken as fuzzy parameters. Also, this method should be assessed on larger multi-objective supply chain optimization problems.

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