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Facility Location Selection for the Humanitarian Needs of Refugees

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Keywords

Humanitarian aid, facility location, goal programming

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Facility Location Selection for the Humanitarian Needs of Refugees

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Abstract

As a result of civil war in Syria and Turkey's open-door policy, almost 3 million refugees moved to Turkey since March 2011. The unexpected arrival of a large number of refugees within a relatively short period of time caused inadequate planning of the government-operated camps to fulfill the humanitarian needs of those affected individuals. The purpose of this study is to develop an optimization model that helps in the distribution of humanitarian aid to the refugees. The multi-objective optimization model decides on the facility locations by integrating total transportation distance minimization and covered demand maximization. Uncertainties in the supply amount are captured through possible scenarios to determine the optimal facilities that will serve the demand points. We used a weighted sum method to solve the multi-objective optimization problem. Different weights are associated with the objective functions to represent the varying preferences of decision makers and examine how the optimal solution changes.

Keywords
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1. Introduction
Many corners of the world seem to be under stress due to man-made reasons such as wars, terrorism, engineering disasters or natural hazards like drought, flood, or earthquakes. These disasters cause huge number of deaths, relocation of thousands of people. World refugee population is rising day by day due to the economic, political or natural reasons. For instance, as a result of the ongoing Syrian war since 2011, many refugees had to leave their country and move to neighboring countries that provide safer conditions. The host countries are challenged to meet the basic needs of this huge number of refugees. Among the basic emergency needs are food, water, sanitation, medication, and shelters. In the case for Turkey, some refugees have relocated to government-operated camps; however, due to the limited capacity of these camps, a high percentage (91%) of the refugees live out of camps, and have difficulty in fulfilling their daily life needs [1].

Whether it is environmental or man-made disasters that lead individuals to flee from their country, the basic humanitarian aid to those in need must be provided. Disaster relief management deals with the process of responding to any catastrophic event such as earthquakes, floods, or wars by ensuring that the humanitarian aid is distributed to those who are impacted [2]. Disaster relief is a multi-phase process which includes mitigation of the disaster effects, increasing the preparedness against disaster, enhancing response to reduce the impact of the hazard, and lastly increasing the recovery activities to restore the affected area back to normal [3]. Disaster management can be classified as pre-disaster and post-disaster activities. Pre-disaster studies focus on the mitigation and preparation process, while post-disaster research deals with the response and recovery stages of the disaster. Disaster management considers the optimization of the humanitarian logistics problems that include evacuation of people from the affected area and efficient planning and control of the distribution of the goods and aid.

The selection of locations for distribution center, warehouse, shelter, medical aid is considered a facility location problem under humanitarian logistics. Studies in facility location determination can be classified depending on the basis of objective function of the problem such as transport distance minimization [4], transport duration minimization [5], transport cost minimization [6, 7], and total covered demand maximization [8]. There are also studies that capture multi-objectives for facility location determination problems. For example, Abounacer et al. [5] proposed a model to determine the number and the location of the distribution centers considering the minimization of total transportation duration and minimization of number of distribution facilities. Barzinpour and Esmaeili [9] developed a multi-objective optimization model that considers both humanitarian and cost constraints for the pre-disaster stage. Ransikarbum and Mason [10] studied the problem of facility location determination under the objectives of maximizing equity and fairness, minimizing uncovered demand, and minimizing total transportation costs. Chanta and Sangsawang [4] developed a model to determine temporary shelters in flood disasters for the post-disaster stage. The objectives were minimizing total distance and maximizing the number of total demand covered.

Due to the stochastic nature of the disasters such as occurrence probabilities, randomness in number of affected people, and status of the evacuation or distribution network, the problem is also modeled by stochastic programming approaches. Murali et al. [8] studied the problem of maximizing the total covered demand under uncertain time and resource conditions for an anthrax attack. Rawls and Turnquist [11] proposed a model for facility location and distribution quantity determination of emergency supplies under uncertain demand and transportation network at the post-disaster stage. Kongsomsaksakul et al. [12] developed a model to determine optimal shelter locations for the flood evacuation. They proposed a bi-leveling programming model for shelter location selection to minimize the total evacuation time.

Our study is under the post-disaster classification and relates to the disaster response phase focusing on the distribution of the humanitarian aid to refugees. The main goal of this study is to optimize the utilization of humanitarian logistics to fulfill the demand. We develop a multi-objective optimization model that determines the distribution locations of the humanitarian aid to refugees. The objective is to decide the optimal number of facilities that minimizes the total transport distance of the aid and maximizes the total covered demand of affected people. We also consider uncertainties in the supply and integrate various supply scenarios to decide for the distribution locations. The study contributes to the literature by both minimizing transportation distance and maximizing covered demand considering the variation in supply amounts in the distribution of the humanitarian aid to refugees. The paper is organized as follows. Section 2 presents the problem and proposes the developed mixed integer programming model. In Section 3, we discuss our solution methodology. Section 4 presents a case study. Section 5 concludes the paper and presents ideas for future extensions.

2. Problem Definition

The purpose of this study is to develop an optimization model that helps the distribution of humanitarian aid to refugees after a post-disaster situation. We identify an optimal way to deliver the food aid to refugees from donors of non-governmental, non-profit humanitarian aid organizations by both minimizing the transportation distance and maximizing the covered demand. It is assumed that the potential facilities are located within the distance limit to cover the demand and there is no facility based fixed cost associated with set up or operating. The problem considers uncertainties in the supply of the food aid. The food aid is distributed to the cities where refugees are densely located. The number of the refugees are gathered from AFAD report [1]; however, the collection of food aid from non-profit, non-government organizations is modeled as a random variable. Considering the various scenarios in supply, the model determines the optimal facilities to distribute the food aid to minimize the total traveling distance and maximize the amount of satisfied demand. In order to solve the problem, we propose a multi-objective mixed integer programming model. The sets, parameters, and decision variables are presented as follows.

Sets

I Set of demand nodes

J Set of facilities

Parameters

D_i Demand in node i

Cap_j Capacity of each facility j

BM: Very big positive number

Dis_{ij} Distance between demand nodes i and facility j

N Maximum number of facilities

Decision variables

$y_{ij} = \begin{cases} 1, \text{ if facility } j \text{ services demand point } i \\ 0, \text{ otherwise} \end{cases}$ $x_j = \begin{cases} 1, \text{ if facility } j \text{ serves refugees} \\ 0, \text{ otherwise} \end{cases}$

Q_{ij} The number of aid boxes transported from facility *j* to demand point *i*

The mixed integer programming model is presented below.

$$\min\ f_1 = E[\sum_{i=1}^{I}\sum_{j=1}^{J} Dis_{ij}Q_{ij}] + E[\sum_{i=1}^{I}\sum_{j=1}^{J}(Q_{ij} - D_i)\cdot Dis_{i1}] \tag{1}$$

$$\max\ f_2 = E[\sum_{i=1}^{I}\sum_{j=1}^{J} Q_{ij}] \tag{2}$$

$$\sum_{j=1}^{J} x_j \le N \tag{3}$$

$$\sum_{j=1}^{J} y_{ij} \ge 1 \qquad \forall i \tag{4}$$

$$\sum_{i=1}^{I} Q_{ij} \le x_j \cdot Cap_j \qquad \forall j \tag{5}$$

$$\sum_{j=1}^{J} Q_{ij} \ge D_i \qquad \forall i \tag{6}$$

$$\sum_{i=1}^{I} D_i \cdot y_{ij} \le Cap_j \cdot x_j \qquad \forall j \tag{7}$$

$$Q_{ij} \le BM \cdot y_{ij} \qquad \forall i, j \tag{8}$$

$$\sum_{i=1}^{I} Q_{ij} \le BM \cdot x_j \qquad \forall j \tag{9}$$

Due to the randomness in the collection of the humanitarian aid, the objective function in equation (1) minimizes the expected total transportation distance. The first expectation includes the calculation of the transportation distance of the food aid boxes from facility *j* to demand node *i*. The second expectation calculates the total transportation distance of the inventory back to the main facility to penalize the overstocked amount. The second objective function in equation (2) maximizes the total number of expected food aid boxes delivered to demand nodes. Constraint (3) shows the upper bound for the number of total facilities. Constraint (4) states that the demand of each node *i* may be delivered by more than one facility. Constraint (5) ensures that the total amount served by facility *j* cannot exceed its capacity. Constraint (6) states that the demand of each node must be satisfied. Constraint (7) guarantees that the capacity of each served facility cannot be exceeded while satisfying the demand. Constraints (8-9) state that only served facilities can meet the demand of node *i*.

3. Methodology

Due to the multi-objective nature of the developed mathematical model, a weighted sum method is used for the optimization process. Weighted sum approach is a common solution procedure for multi-objective optimization problems [13]. In this method, the decision makers have the liberty of prioritizing the objectives according to their preferences. Multi-objective functions are transformed into a single objective function with weights assigned for each objective as follows (equation 10). In equation (10), f_i refers to the i^{th} objective function and w_i shows the weight of i^{th} objective function.

$$\max\ \sum_{i=1}^{I} w_i \cdot f_i \tag{10}$$

Each objective function f_i is solved under the constraints (3-9) separately first, and the positive ideal solutions (best solution) are found. Then, the decision variables of each solution are inserted as an input, and the model is solved by considering the remaining objective functions. The procedure is repeated until the model is solved for all objective functions. Among all the solutions, negative ideal solution (worst) is found for each objective function. Since objective functions vary on different scales, normalization is applied to present each objective function on the same scale. Equation (11) presents the normalization for both minimization and maximization objective functions. In equation (11), WS_{f_i} and BS_{f_i} present the worst and the best solutions of the objective function f_i, respectively.

$$f_i^{'} = \begin{cases} \dfrac{WS_{f_i} - f_i}{WS_{f_i} - BS_{f_i}}, & \textit{for minimization} \\ \dfrac{f_i - WS_{f_i}}{BS_{f_i} - WS_{f_i}}, & \textit{for maximization} \end{cases} \tag{11}$$

The single objective function f is the weighted sum of each normalized objective function, $\max\ f = \sum_{i=1}^{I} w_i \cdot f_i^{'}$. However, in the proposed model given in equations (1-9), the number of aid boxes collected for each facility is a random variable; therefore, we model the objective functions as an expectation. The single objective function for the developed model is:

$$\max\ E[f] = \sum_{i=1}^{I} w_i \cdot E[f_i^{'}] \tag{12}$$

In order to calculate each expected objective function $E[f_i]$, random scenarios for the number of collected aid boxes Ω_s with the respective probabilities P_s are generated, $\Omega_s = \{A_{1s}, A_{2s}, ..., A_{js}\}$, where s shows each scenario and S refers to the total number of scenarios. Then, the expectations of each objective function f_i are calculated separately, using $E[f_i] = \sum_{s=1}^{S} P_s f_i(\Omega_s)$. For each optimization problem $E[f_i]$ refers to the best solution as BS_{f_i}. Including the solution of each objective function x_{ij} – optimal facilities that will serve the demand points – as inputs for the second optimization problem, the problem is again solved for the same scenarios and the expected worst case objective function WS_{f_i} is calculated. By applying the normalization in equation (11), the objective functions are normalized and transformed into a single objective function as provided in equation (12). A solution of the optimization problem by maximizing the weighted sum of all objective functions provides the optimal facility locations that will serve each demand point.

4. Case Study

We consider five cities that have the highest refugee population and determine the optimal facilities that minimize the total transport distance and maximize total covered demand. Table 1 presents the refugee population in the cities which have the highest number of refugees. These cities are considered as demand nodes and represented by D1,…, D5. The food aid is collected from non-government, non-profit organizations and donors in a standard package, and then distributed to each city. We assume that the demand in each city is equal to the refugee population. A goal programming model is developed in order to both minimize the transport distance between facilities and the demand nodes and maximize the amount of covered demand.

Table 1: The refugee population in the top five cities where the refugees are located.

Cities	Refugee population
Istanbul (D1)	483,490
Hatay (D2)	319,522
Gaziantep (D3)	369,898
Sanliurfa (D4)	293,531
Adana (D5)	159,214

There are six potential cities where the facilities may be located: Istanbul, Ankara, Konya, Kayseri, Antalya, and Gaziantep. We used abbreviations to represent them as F1,…, F6. The facility capacity for both Istanbul and Ankara is 850,000 unit of boxes and the capacity of other facilities is 800,000 units of boxes. These potential facilities are selected according to their distance to the demand points, and their high population which may increase the total amount of aid collected. Moreover, these facilities are located within the distance limit to serve the demand nodes. In the model, the amount of the aid collected is considered as a random variable. We assume that the total amount of the collected aid will be a percentage of the facility capacity ─ 100%, 90%, 80%, 70% and 60% of the facility capacity. Various scenarios are generated in equal probability to simulate the amount of aid collected in Table 2. The actual distances between potential facility locations and the demand nodes are listed in Table 3.

Table 2: Possible supply scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	Supply amount (100% of cap.)	Supply amount (90% of cap.)	Supply amount (80% of cap.)	Supply amount (70% of cap.)	Supply amount (60% of cap.)
Istanbul (F1)	850,000	765,000	680,000	595,000	255,000
Ankara (F2)	850,000	765,000	680,000	595,000	255,000
Konya (F3)	800,000	720,000	640,000	560,000	240,000
Kayseri (F4)	800,000	720,000	640,000	560,000	240,000
Antalya (F5)	800,000	720,000	640,000	560,000	240,000
Gaziantep (F6)	800,000	720,000	640,000	560,000	240,000

Table 3: The distance between potential facilities and the demand nodes in km.

	Istanbul (F1)	Ankara (F2)	Konya (F3)	Kayseri (F4)	Antalya (F5)	Gaziantep (F6)
Istanbul (D1)	-	449	710	772	696	1147
Hatay (D2)	1100	655	513	408	775	167
Gaziantep (D3)	1146	701	559	336	821	-
Saniurfa (D4)	1288	843	701	482	963	151
Adana (D5)	932	489	348	304	606	223

We use the weighted sum method discussed in Section 3. In the study, it is assumed that maximizing the covered demand by the refugees has a higher priority than minimizing the total transportation. In the first set of experiments, the weight of maximizing the fulfilled demand is 0.7, while the weight of minimizing the travel distance is equal to 0.3. The goal programming model is solved and the results are presented in Table 4.

Table 4: Optimal solutions for the facility location problem

	Single objective function		Multi-objective function
	Min f_1 (transport distance)	Max f_2 (covered demand)	Max $= f_1^{'} + f_2^{'}$ (weighted sum)
Facilities	F1, F4, F6	F1, F2, F3, F4, F5, F6	F1, F2, F3, F4, F5, F6
Solutions	$E[f_1] = 238{,}849{,}500$ (best)	$E[f_1] = 3{,}920{,}759{,}000$ (worst)	$E[f_1] = 1{,}098{,}426{,}280$
	$E[f_2] = 1{,}625{,}655$ (worst)	$E[f_2] = 3{,}280{,}130.4$ (best)	$E[f_2] = 2{,}028{,}283.87$
			$E[f_1^{'}] = 0.766$ $E[f_1^{'}] = 0.24$
	$E[f_2^{'}] = 0.501$	$E[f_1^{'}] = 0.451$	$E[f] = 0.389$

In Table 4, the second and third columns represent the optimal facilities that will serve to meet the demand of refugees, and the best and worst objective function values. Once the objective is to minimize the total transport distance; facilities F1, F4, and F6 will serve the demand points. The minimum transportation distance is 238,849,500 km. When the served facilities F1, F4, and F6 are inserted as inputs to the second optimization problem, i.e., maximizing covered demand, the expected amount of the fulfilled demand is 1,626,655 unit of boxes, which is the worst expected solution for the second optimization problem. In the third column, the problem is also solved solely for maximizing the total covered demand. According to the solution, all facilities will serve the demand nodes. The expected maximum covered demand is 3,280,130.4 unit of aid boxes. While all the facilities serve the demand points, the expected total traveling distance is 3,920,759,000 km, which is the worst case solution for the minimization problem. After normalizing the objective functions through equation (11), the multi-objective function is solved under relative weights of 0.7 and 0.3 for the maximization and minimization problem, respectively. The last column in Table 4 shows the optimal facilities that will serve refugees and the expected objective function values of the minimization and the maximization problems. The last row shows the expected normalized single and multi-objective function values. The normalized objective function values show how close the solution to the ideal objective function is. For instance, $E[f_2^{'}] = 0.501$ shows that in the transportation minimization model, the objective function of the covered demand maximization problem reaches 50.1% of its ideal solution.

In the following numerical study, the relative weights of the objective functions are assigned and the sensitivity analysis is performed to investigate the change in the optimal facility location with respect to the prioritization of the decision maker. Table 5 presents the results for the various weights associated with the objective functions. Depending on the relative importance of the objective functions, decision makers choose the optimal facility locations that will serve the demand nodes.

Table 5: Optimal solutions for various weights associated with the objective functions

	Multi-objective function, Max $= f_1^{'} + f_2^{'}$ (weighted sum)			
	$w_1 = 0.3$ $w_2 = 0.7$	$w_1 = 0.5$ $w_2 = 0.5$	$w_1 = 0.6$ $w_2 = 0.4$	$w_1 = 0.7$ $w_2 = 0.3$
Facilities	F1, F2, F3, F4, F5, F6	F1, F2, F3, F4, F5	F1, F2, F3, F4, F5	F1, F3, F4, F6
Solutions	$E[f] = 0.389$	$E[f] = 0.452$	$E[f] = 0.537$	$E[f] = 0.771$
	$E[f_1^{'}] = 0.766$	$E[f_1^{'}] = 0.000$	$E[f_1^{'}] = 0.000$	$E[f_1^{'}] = 0.226$
	$E[f_2^{'}] = 0.240$	$E[f_2^{'}] = 0.904$	$E[f_2^{'}] = 0.896$	$E[f_2^{'}] = 1.000$
	$E[f_1] = 943{,}005{,}040$	$E[f_1] = 792{,}900{,}120$	$E[f_1] = 494{,}698{,}020$	$E[f_1] = 321{,}077{,}240$
	$E[f_2] = 1{,}951{,}388.35$	$E[f_2] = 1{,}793{,}938.84$	$E[f_2] = 1{,}625{,}655$	$E[f_2] = 1{,}698{,}981.79$

5. Conclusion

This study presents a multi-objective optimization model that decides the number and the location of the facilities for the distribution of the humanitarian aid to refugees in Turkey. An optimal facility determination model is developed to ensure that the aid is distributed with minimum transportation distance and in maximum quantities of fulfilled demand. We also consider the uncertainty in the supply of the aid from non-governmental and non-profit organizations. Under various supply scenarios, the multi-objective optimization model is run and the optimal facilities are decided under different decision maker preferences on the objectives.

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