Journal of Industrial and Systems Engineering
Vol. 10, No. 1, pp 1-17
Winter (January) 2017

A customized bi-objective location-routing problem for locating post offices and delivery of post parcels

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Abstract

One of the most important problems for distribution companies is to find the best locations for depots and to find proper routes for transportation vehicles to optimize their supply network. This study intends to develop a model for the problem of location-routing in post offices. So, a new bi-objective location-routing problem for locating town post office and routing parcels is defined. This problem is modeled through the mixed-integer mathematical programming. The aim of the proposed model is to select potential post offices and to find optimal routes for transportation vehicles whiletime constraints are taken into account. The proposed model is applied in a real case study including eight main post area and 21 regional offices in Tehran, Iran. A goal programming approach is proposed to solve this bi-objective optimization model. An optimization Software is used to code and solve the associated mathematical model. Some required parameters of the model such as demands are estimated using Geographical Information System (GIS) and simulation methods. The results of proposed model including the objective functions, decision variables, and proposed routing of vehicles have been compared with the existing practical solutions. Sensitivity analysis on main parameters of the proposed models is accomplished and the results are analyzed. This comparison illustrates the efficacy and applicability of our proposed approach.

Keywords: Location-routing problem, post office location-routing, bi-objective optimization, goal programming, Tehran post office.

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ISSN: 1735-8272,

1- Introduction

Location-routing problem (LRP) is a combination of two types of planning. In LRP, decisions are made about the location of facilities (equipment, stops, depots, storages, points, etc) and the routes of transportation vehicles. Finding a proper solution for LRPs can help managers to make right decisions about the positions of facilities (distribution centers and depots) and transportation plans. The main difference between LRP and classic location problem is that in the former (after determining the positions of facilities), the routes among customers and facilities are considered as a network; on the other hand, in the latter, it is assumed that there are direct routes among customers and facilities. This increases the distribution's costs. Therefore, in contrast to traditional location problem, in location-routing problem, the aim is to find the optimal locations for facilities and also the optimal routes. Maranzana (1964) noted that the costs of transportations are highly affected by the location of factories, depots, and distribution centers.

LRP has a lot of applications in the real world, one of which is its application in post distribution systems. In fact, in such networks, the locations of facilities must initially be selected in order to have easy access to sub-locations and customers. Then, the best routs must be found for the delivery and the collection of postal parcels. Looking at the structure of post distribution networks reveals that there is a very close relationship between such networks and the structure of LRPs. First, in the postal systems, the locations of facilities (or post offices) are selected. In the process of location-selection, some parameters are important, such as the location of offices, accessibility, etc. If proper locations are selected for post offices, finding the optimal routes for the shipment of postal parcels is faster, easier, and cheaper. A number of parameters are important in the process of routing, such as time constraints, type of transportation vehicle, traffic, and type of post services requested by the customer. Based on the above-mentioned issues, an efficient location-routing method in post system reduces various expenses and increases customer satisfaction. Burns et al. (2000) were among the first researchers who studied the problem of location-routing in post distribution systems. Their study was done in the post network of Switzerland. The aim of their study was to solve location problem and to minimize expenses.

Since an efficient system for distribution of postal parcels is crucial in large cities, managers have to design macro-plans to improve the efficiency of post system. Tehran, as a metropolitan, is not an exception. Since Tehran is among the high-crowded cities, an efficient plan is necessary for finding the proper locations of post offices and the best routes for transportation vehicles. This study is conducted in Tehran Post Office (TPO), which includes 8 main post areas. These areas are associated with post offices (minor areas). Every post office is considered as a subset or a branch of a main post area.

As mentioned, Tehran has eight main post areas, each one including a number of post offices. The number of these offices in each area is dependent on the size of the area and its population. There are 21 regional offices across Tehran. The main post center distributes postal parcels among post areas and also receives and collects parcels sent from these areas. The received parcels are prepared to be sent to other cities. The routes for the transportation of postal parcels are selected on the basis of pervious planning in order to prevent any delay in delivering postal parcels. Figure 1 shows the schematic view of eight main post areas in Tehran.

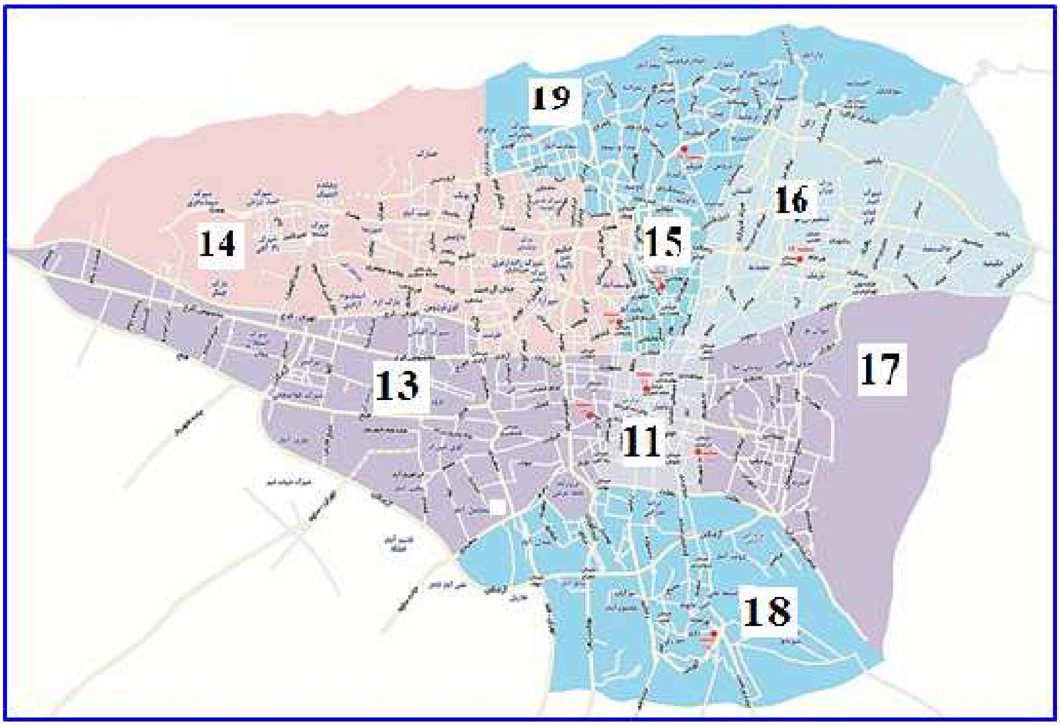

Fig.1. Areas of Tehran Post Office

LRP has a lot of applications in daily life of people. This study intends to show the importance and applications of this problem in post distribution systems. Finding a solution for this problem makes it possible to offer better services to the people. Because of the largeness of post distribution systems and the nature of their services, a lot of problems are observed in these systems. By a full description of the problem and finding the source of the problems, we might obtain an optimal solution in order to reduce the costs. The expenses of transportation in post systems and post offices are clear. Sine this research intends to find the best locations for post offices and the best routes for the transportation of postal parcels, it may offer an efficient solution for some problems in the post system.

The next sections of this paper are organized as follows. In Section 2, a brief literature of related past research works is reviewed. In Section3, the mathematical model of the study is proposed and the solution procedure is also presented. In Section 4 the case study and the results are discussed. Finally, in Section 5 the conclusion remarks and future research direction are presented.

2- Review of literature of past works

The idea of combining location and routing problems originates from an article written by Maranzana (1964). Transportation costs are highly correlated with the location of factories, depots, and supply centers. The work by Maranzana (1964) is considered to be the first article written on location-routing problem. However, it only focused on finding the shortest route and the locations. Rond (1976) observed that some experts were aware of the danger of not paying simultaneous attention to locations and routing. However, the relation between these two subjects was usually neglected and many experts tried to solve the problem of location without the inclusion of routing.

The first exact algorithm for the solution of LRP was proposed by Laporte and Nobert (1981). In their study, a station was chosen and several transportation vehicles were used. They employed Branch and Bound (B&B) Algorithm. They found that rarely the best location for the station is the closest knot to the center of gravity. Laporte et al. (1983) examined the location problem of several stations with fixed expenses. In that problem, there was only one vehicle at the station and the assumptions of excluding minor trips were taken into account.

Ting and Chen (2013) suggested an Ant Colony Algorithm for solving LRP. They used 3 ant colonies for the location of facilities, directing passengers, and routing. The first colony opened a number of facilities and selected them on the basis of pheromone data, the proportions of facility capacity, and expenses of reopening. The second colony directed the passengers on the basis of pheromone data and their distance from facilities. The mechanism of repair was used handling the constraints of facility capacity. Therefore, the first two colonies produced a solution for facility location problem (FLP). The third ant colony focused on producing a solution for vehicle routing problem (VRP) for every facility and its passengers. Routes were selected on the basis of economic considerations and pheromone data.

Jarbouri et al. (2013) suggested Variable Neighborhood Search (VNS) Algorithm for LRP considering no capacity limitation. They employed Variable Neighborhood Descent (VND) Algorithm as a part of least squares method. They proposed five variables for this method of solution. The first four variables were related to passengers (passenger entrance, exchange, passengers' sequential entrance, reversed sequential entrance). These four variables were used for inter-routes and intra-routes. The fifth variable was related to the closing of a facility and the opening of other facilities in a random manner. In their numerical calculations, they concluded that by using semi-random strategy, the movement stage produced the best results.

De Camargo et al. (2013) studied 'many-to-many location-routing problem' (MMLRP). They assumed that exactly one depot should be assigned to one passenger. Every passenger should use a depot one time. The location of a passenger is considered as a main location. Their aim was to minimize the expenses of establishing the centers, management expenses for transferring goods to the depots, fixed expenses of assigning vehicles to opened depots, and expenses related to the distances in the routes. They combined the suggested model with the model of Traveling Salesmen Problem (TSP). A satisfactory optimal solution was found by branch and cut method. In order to test the model, they used depot locating problems with 10-100 passengers. The largest problem which was optimally solved by analysis algorithm had 100 passengers. This was an outstanding result, because the problem with 100 passengers was consistent with the problem with ten thousand goods items.

ZareMehrjerdi and Nadizadeh (2013) studied LRP considering unclear demands as fuzzy variables. In order to solve the problem, they used Nadizadeh's (2009) clustering method, which was suitable for fuzzy problems. In order to find the real demands of passengers, probability simulation was used. The method was used for three problems. They posed this question that whether a vehicle should return to the facility and board passengers to its full capacity. The results obtained by this method were compared without taking into account the capacity of vehicles and facilities.

Hashemi Doulabi and Seifi (2013) studied location arc-routing problem (LARP) considering no capacity limitations. Their aim was to reduce the total expenses of establishing and installing facilities and also fixed and variable expenses of vehicle routing. They considered an upper border for a number of open facilities and a number of routes which had been selected for each facility. They suggested two formulas: one for the time that one facility is open and another one, for the time that several facilities are open. They combined this formula with several variables in order to solve the problem rapidly. To solve the problem, they suggested a repetition process with a combination of arch-variable approach and location assignment. The first thing to do was to visit the route and assigned it to the closest facility. At each stage, LARP was considered as the gate of that route which can go beyond the upper limit of a number of facility routes and combine with each other one by one. Location assignment approach repetitively showed facilities open and close. It assigned routes to various facilities. Routing and location assignment continued until the time that no progress was observed.

Govindan et al. (2014) investigated two-echelon LRP within a time-window. They opened the facilities of echelons considering fixed expenses. Routes were calculated at two echelons and two objectives were investigated: (1) Reducing the overall of fixed costs of re-opening of facilities and variable expenses of routing of vehicles; (2) The impact of the system on environment. These researchers presented a complex integer programming model on the basis of arch-variables with 49 types of equation. The calculations were made for 12 random samples with 4-12 zero-echelon fleets, 8-18 one-echelon fleets, and 12-30 passengers. By taking into account the four various functions of the model, it was compared with multi-objective genetic algorithm.

Rieck et al. (2014) studied many-to-many LRP with several types of goods and the possibility of movement between collection and delivery locations. Various types of goods were produced in one or several locations. Also, every type of goods could be requested by one or several locations. There was a fleet of similar vehicles at the center. These vehicles could go through three types of route: (1) Multi-station pick up route which in which the vehicles began emptily, and (before delivering any passenger) passed one or several locations and then returned to the center fully or emptily; (2) Direct routes between departure and arrival centers; (3) Multi-station delivery routes which are filled by one center and, before delivering any passenger, pass one or several locations and embark passengers and finally returned to the center emptily. Every vehicle went into one rout. Also, it had to move along the routes continuously until it reached to its destination.

Burns et al. (2000) studied post parcels delivery problem. In their research, postal parcels were directly sent from post centers to postal parcels processing centers. Finally, they were sent to delivery units. These postal parcels were delivered to the customers by vehicles that passed several stations (processing centers were delivery depots). The objective was to select the locations of delivery and transportation of post parcels toward processing centers and delivering post parcels to the customers. In this problem, routes were the mediations between customers and delivery centers. Burns et al. (2000) modeled the case using LRP. They included the expenses into the problem and calculated an approximation of these expenses. Regarding the expenses of routing, an approximation of the length of route must be included into the problem. In this way, the problem of location-routing was made smaller and was turned into a location problem of a simple system. The problem was solved by Branch and Bound method.

Wasner and Zapfel (2004) investigated parcel service problem which was closely related to many-to-many LRP. Vehicles had to pick up and to deliver the parcels. The main location and the routes had to be selected. All depots had to be connected to each other by the mediation of a center. In this problem, a hierarchical approach was used. The routes of vehicles were selected by a heuristic method.

Lischak and Triesch (2008) investigated many-to-many LRP postal parcel services. Postal parcels were directly transferred among depots. Locations of the majority of depots which were connected to each other by the center were initially selected. Without any regard to the locations of other depots, the capacity of all depots had to be determined. They counted depots and used pick up-and-delivery method to calculate routing expenses. Also, they obtained an approximation of the length of the route.

Hosseininezhad and Jabalameli (2016) presented a multi-objective continuous covering location problem in fuzzy environment. The presented model was an extension of the discrete covering location models to continuous space. A fuzzy programming was applied for converting the model to a single objective one. Finally, a numerical example with sensitivity analysis was expressed to illustrate the presented model. Kordjazi and Kazemi (2016) proposed a three-objective model in location-allocation problems using combinational interval full-ranking and maximal covering with backup model. Mohamadi and Yaghoubi (2016) proposed a multi-objective model to determine the location of transfer points and hospitals to provide timely quick reaction for treating injured people as well as to determine unreliable and reliable depots for the distribution of medicines and medical equipment. To solve the model, the hybrid meta-heuristic algorithm was proposed.

Based on review of past literatures, several gaps are recognized in LRPs. Multi-objective variants of LRPs have received less attentions during past years. Although, the real applications of LRPs are involved in multiple objective problems. Uncertainty is another concepts existing in most to the all of LRPs in real life problems. For instance, demand, facility availability, routing, and cost parameters usually are mixed with a great amount of uncertainty. Unfortunately, there were low numbers of uncertain LRPs in literature of past works. Few studies have been done on location arc-routing problem. Since this problem has a lot of applications in urban distribution systems and also post systems, more work is needed to be done on this problem.

In this study, we are going to develop and customize a bi-objective LRP in order to locate sites of post offices and to route the parcels from post offices toward customers using fleet of vehicles. Several practical constraints will be considered in the proposed model.

3- Proposed model and solution procedure

In this section, a model is proposed in order to handle the post office location and routing of post parcels. The proposed model is a bi-objective mixed integer mathematical programming optimization which considers several practical real world constraints. The first and second objective functions are minimizing the total cost of the system and minimizing the total delivery time of parcels to customers, respectively. These two objective functions are conflictive. On the other hand, minimizing the total cost of the system will increase the delivery time, and minimizing the delivery time will increase the total cost of the system. Under such situation, finding compromise solutions on the Pareto front of the problem is interesting. Several set of constraints are associated to the vehicles, customers, and locations on the basis of real world situation.

3-1- Problem assumptions

Assumptions of the proposed model are summarized as follows:
-Candidate locations for post offices are fixed during the period of planning.
- Customer demands in each region are known and estimated during the period of planning.
- Costs of potential post areas are known and fixed during the period of planning.
- Every vehicle belongs to only one post area.
- Parcels of all customers must be delivered during the period of planning.
- Route begins from a distribution center and ends in the same center.
- There is a maximum permissible delay for the delivery of parcels to the customers.
- The average speed of vehicles throughout the route is known and fixed.
- Transportation routes are known and fixed during the period of planning.

3-2- Notations

The notations used in the proposed model are presented as follows.

Sets:

I Set of potential location nodes $I=1,\ldots,m$
J Set of customer nodes $J=1\ldots.,n$
K Set of vehicles $K=1,\ldots,k$
V Sets of customer nodes and location nodes $I\cup J$

Parameters:

N Number of customers
K Number of vehicles
O_i Fixed cost of establishing the location in site i
P_k Transportations cost of vehicle k
q_{ij} Fixed cost of transporting parcels from site location $i$to customer j
d_{ij} Distance between location $i$and location j
t_{ijk} Time of traveling from location i to location j by vehicle k
E_k Maximum permissible length of the route for vehicle k

Decision Variables:

$$X_{ijk} = \begin{cases} 1 & \text{If vehicle } k \text{ goes directly from location } i \text{ to customer } j \\ 0 & \text{Otherwise} \end{cases}$$

$$Y_i = \begin{cases} 1 & \text{If a location is established in site } i \\ 0 & \text{Otherwise} \end{cases}$$

$$Z_{ij} = \begin{cases} 1 & \textit{If } \text{customer } j \text{ receives services from location } i \\ 0 & \text{Otherwise} \end{cases}$$

$T \geq 0$, Time of offering services to customers

3-3- Mathematical model

Considering the problem assumptions and notations, the following bi-objective mixed integer mathematical programming Model is proposed to handle the location of post offices and routing of post parcels.

$$\min f_1(y,z,x) = \sum_{i\in I} O_i y_i + \sum_{i\in I}\sum_{j\in J} q_{ij} z_{ij} + \sum_{k\in K}\sum_{i\in V}\sum_{j\in V} P_k d_{ij} x_{ijk} \tag{1}$$

$$\min f_2(T) = T \tag{2}$$

s.t.

$$\sum_{k\in K}\sum_{i\in V} x_{ijk} = 1 \quad \forall j\in J \tag{3}$$

$$\sum_{i\in V}\sum_{j\in V} d_{ij} x_{ijk} \leq E_k \quad \forall k\in K \tag{4}$$

$$\sum_{i\in V}\sum_{j\in V} t_{ijk} x_{ijk} \leq T \quad \forall k\in K \tag{5}$$

$$\sum_{j\in V} x_{ijk} - \sum_{j\in V} x_{jik} = 0 \quad \forall i\in V, k\in K \tag{6}$$

$$\sum_{i\in I}\sum_{j\in J} x_{ijk} \leq 1 \quad \forall k\in K \tag{7}$$

$$\sum_{i\in S}\sum_{j\in S} x_{ijk} \leq |S|-1 \quad \forall S\subseteq J, k\in K \tag{8}$$

$$\sum_{u\in J} x_{iuk} + \sum_{u\in i} x_{ujk} \leq 1 + z_{ij} \quad \forall i\in I, j\in J, k\in K \tag{9}$$

$$\sum_{k\in K}\sum_{j\in J} x_{ijk} = y_i \quad \forall i\in I \tag{10}$$

$$\sum_{k\in K}\sum_{i\in I}\sum_{j\in I} x_{ijk} = 0 \tag{11}$$

$$x_{ijk} \in \{0,1\} \quad \forall i\in V, \mathrm{j}\in V, k\in K \tag{12}$$

$$y_i \in \{0,1\} \quad \forall i \in I \tag{13}$$

$$z_{ij} \in \{0,1\} \quad \forall i \in I, j \in J \tag{14}$$

$$T \geq 0 \tag{15}$$

3-3-1- Description of proposed model

Objective function (1) minimizes overall cost of the system, which includes the cost of establishing distribution centers and cost of delivering parcels to the customers as well as transpiration costs. Objective function (2) minimizes the maximum time of delivering parcels to the customers in a route. Set of constraints (3), which is written for each customer, guarantees that every customer uses only one vehicle. Set of constraint (4), which is written for each vehicle, guarantees the maximum length of route for every vehicle. Set of constraint (5), which is written for each vehicle, guarantees that the transportation time for every vehicle is limited and must be lower than a given time T. Set of constraint (6), which is written for each site location i, and each vehicle *k*, guarantees that every vehicle must meet a customer before leaving that location. Set of constraint (7), which is written for each vehicle, guarantees that every vehicle returns to the same location from which it begins its movement. Set of constraint (8) guarantees sub-tour elimination in final solution of the model. Set of constraint (9), which is written for each customer *j*, each site location *i*, and each vehicle *k*, guarantees that a given customer can be assigned to a given location if there is passing route from customer to location (or vice versa) using vehicle *k*. Set of constraint (10), which is written for each site location *i*, guarantees that if a location is established, a vehicle is certainly assigned to it. Set of constraint (11) guarantees that there is no direct route from one location to another location. Set of constraint (12), (13), and (14) defines the domain of decision variables. Constraint (15) guarantees that the maximum time of delivery to customer is a continuous positive variable.

Due to our best knowledge customizing Model (1)-(15) has some new insights in the field of planning in post offices which can be summarized as follows:

- Incorporating two objective functions (i.e., total cost, and delivery time) has never been considered in previous work in the field of post office planning.
- Set of constraint (4), which guarantees the maximum length of route for every vehicle, has never been considered in the field of post office planning while it is an essential constraint in real world.
- Set of constraint (5), which guarantees that the transportation time for every vehicle is limited and lower than a given time has never been considered in the field of post office planning while it is an essential constraint in real world.

3-4- Solution procedure

When a mathematical programming has more than one objective, i.e., the multiple-objective programming, the objectives may show conflictive behavior in a way that optimizing all of them cannot be accomplished through one unique feasible solution. In such cases multiple-objective decision making (MODM) techniques may be utilized. Goal Programming (GP) is among the well-known MODM technique which makes generating compromise solutions of a multiple-objective programming possible.

The main aim of GP is to achieve a set of objectives simultaneously (Charnes and Cooper, 1955). This method was initially used by Charnes and Cooper (1961). Then, a number of other researchers such as Lee (1972), Ignizio (1976), Romero (1991), and Cavalier (1994) employed this method. It has been proven that GP is consistent with the concept of Pareto optimization (Jones and Tamiz, 2010).

3-4-1- Weighted Goal Programming

In weighted GP, a certain value is selected as the goal for every objective. Then the related objective function is formulated. The aim is to find an answer which minimizes the weighted sum of deviations of each objective from its associated goal. In order to express the problem by a mathematical language, assume that $x_1, x_2, x_3, \dots, x_n$ are decision variables, K is the number of objectives, $C_{jk}(j = \{1,2,..,n\})$ is the j-th coefficient decision variable in the objective function k(k=1, 2, …, K), and g_k is the selected goal for k-th objective. It is intended to find an answer which is as much as possible close to the goals as demonstrated in Equations (16)-(18).

$$\sum_{j=1}^{n} c_{j1} x_j = g_1 \qquad \text{First goal} \qquad (16)$$

$$\sum_{j=1}^{n} c_{j2} x_j = g_2 \qquad \text{Second goal} \qquad (17)$$

$$\vdots \qquad\qquad \vdots$$

$$\sum_{j=1}^{n} c_{jk} x_j = g_k \qquad \text{goal } k \qquad (18)$$

Since simultaneous examination of all goals is not possible, GP can be formulated in the following way in which the objective is to minimize the sum of deviations from goals.

$$Z = \sum_{k=1}^{K} \left| \left(\sum_{j=1}^{n} c_{jk} x_j - g_k \right) \right| \qquad (19)$$

The absolute term in (19) can be replaced with the help of some new auxiliary positive decision variables. Z in (19) can simply be re-formulated using (20)-(21).

$$y_k = \sum_{j=1}^{n} c_{jk} x_j - g_k \quad (k = 1, 2, ..., K) \qquad (20)$$

$$Z = \sum_{k=1}^{n} | y_k | \qquad (21)$$

Since y_k can take positive and negative values, their positive and negative elements can be replaced with $y_{k^+}, and y_{k^-}$ as positive variables, respectively. So, y_k can be rewritten as (22).

$$y_k = y_{k^+} - y_{k^-}, \quad y_{k^+} \geq 0, \quad y_{k^-} \geq 0 \qquad (22)$$

The GP model can be written as (23)-(26)

$$Minimize \quad Z = \sum_{k=1}^{K} (y_{k^+} - y_{k^-}) \qquad (23)$$

$Subject\ to$:

$$\sum_{j=1}^{n} c_{jk} x_j - (y_{k^+} - y_{k^-}) = g_k \qquad (k = 1, 2, ..., K) \qquad (24)$$

$$y_{k^+} \geq 0, \ y_{k^-} \geq 0, \ (k = 1, 2, ..., K) \qquad (25)$$

$$x_j \geq 0 \qquad (j = 1, 2, ..., n) \qquad (26)$$

Usually, in real cases, some objectives have a higher significance compared to the other objectives. In addition, in a particular case, deviation from ideal in one direction might be more significant compared to another direction. These differences can be included in the formulation by the help of weighted coefficients (W_{k^+}, W_{k^-}), which are related to variables y_{k^-} and y_{k^+}, respectively. These weighted coefficients measure the relative significance of results of deviations. Therefore, main objective of GP can be written as (27).

$$Minimize\ \ Z = \sum_{k=1}^{K} (W_{k^+} y_{k^+} + W_{k^-} y_{k^-}) \tag{27}$$

4- Case study and results

4-1- Case study of Tehran post offices

The proposed model of this study is implemented in a real case study of Tehran post offices in order to optimize the location of post offices and to improve the routing of post parcels. More formally, the problem is how to select locations for Tehran Post Office and how the routes of post parcel must be chosen. In other words, we intend to select a number of locations from among the potential locations for post offices and also choose optimal routes for vehicles. There are 8 candidate locations for post offices in Tehran. These new candidate locations have been shown in Figure 2 using red stars.

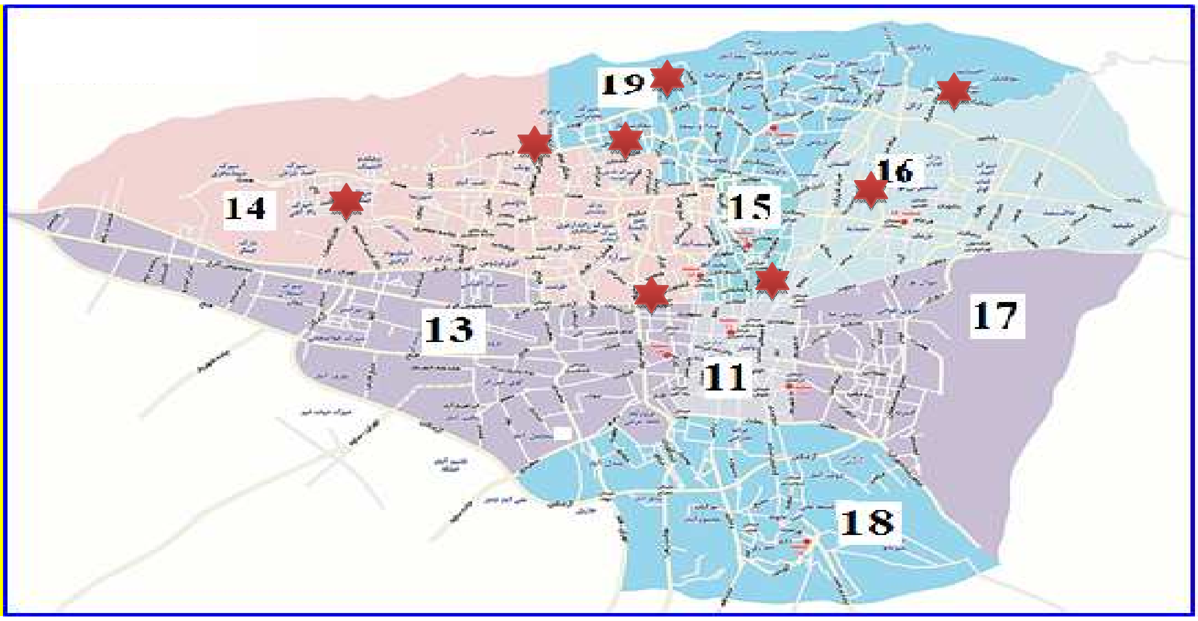

Fig.2. Candidate locations for establishment of post office (showed by stars)

Since the number of customers of Tehran Post Office is large enough, non-deterministic and usually follows a probability distribution function, number of customers who received services in all post areas of Tehran in last 12 months was considered as the sample to estimate the demand of areas. The geographic coordination of all demand records during these 12 months was determined in Tehran. Then, map of Tehran was gridded into 20 equal areas using horizontal and vertical lines as shown in Figure 3. Number of request in each grid divided to all requests during the last 12 months was assumed as an estimated probability of a request from a grid. The center of gravity of requests in each grid was calculated using geographical coordination of grids and the estimated probability. Twenty centers are shown in Figure 3 using blue stars. These star centers are good estimation of requests in each area.

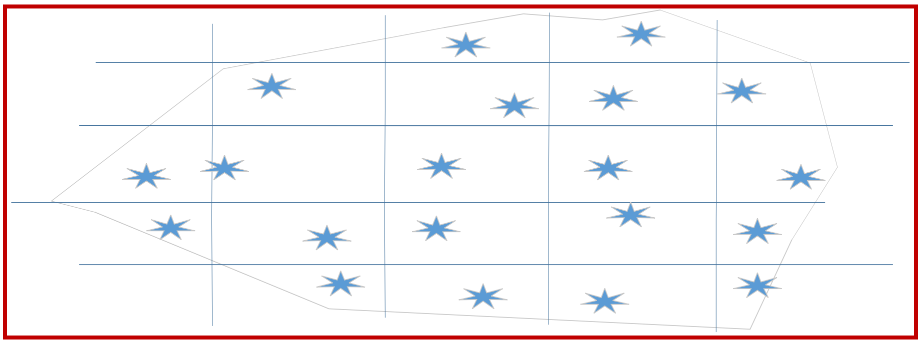

Fig. 3. Estimated Demand Point of customers of Tehran Post Office

Based on Figure 2, and Figure 3, the associated problem of the case study contains 20 demand nodes and 8 candidate locations for establishment of sites.

4-2- Associated weighted GP for proposed model

The following GP model (28) is proposed for solving the proposed Model (1)-(15).

$$Min = \left(\frac{d_1^+}{Cost^{\max} - Cost^{\min}}\right) \times w_1 + \left(\frac{d_2^+}{T^{\max} - T^{\min}}\right) \times w_2$$

$$f_1(y, z, x) - d_1^+ + d_1^- = g_{Cost}$$

$$f_2(T) - d_2^+ + d_2^- = g_T$$

$$X \in FS \qquad (28)$$

Where, $d_1^+$is a positive decision variable associated with the positive deviation from the goal of first objective, d_1^- is a positive decision variable associated with the negative deviation from the goal of first objective, d_2^+ is a positive decision variable associated with the positive deviation from the goal of second objective, d_2^- is a positive decision variable associated with the negative deviation from the goal of first objective, $Cost^{\max} - Cost^{\min}$ is range of first objective function (1), $T^{\max} - T^{\min}$ range of second objective function (2), g_{Cost} is the goal value for the first objective function, g_T is the goal value for the second objective function, $f_1(y, z, x)$ is the equation of first objective function (1), $f_2(T)$ is the equation of second objective function (2), $X \in FS$ refers to constraints (3)-(15), and w_1 and w_2 are the relative importance of deviation from the goals of the first and second objective functions, respectively.

It is notable that dividing the $d_1^+$to $Cost^{\max} - Cost^{\min}$, and also d_2^+ to $T^{\max} - T^{\min}$ results a common range for both objective functions and make the summation meaningful. The ranges of both objective functions have been calculated using single optimization of each objective function. The Model (28) was codified in GAMS Software. The results will be presented in the following sections.

4-3- Results

The results of single-objective optimization for the first and second objectives on case study have been presented in Table 1. In the single-objective optimization of cost, it is expected that only one depot to be activated for the minimization of expenses. As can be seen in the Table 1, the maximum time of trip is 141 hours, which is considered to be high. On the other hand, in the single-objective optimization of time, expenses are increased up to ten times, and the maximum time of routes is reduced to one-tenth. In this condition, all depots are active and there are 8 different routes for offering services to customers.It is notable that the weights of objective functions are equally set to 0.5 on the basis of experts in Tehran post office administration center.

Table 1. Results of single-objective minimization on the case study

	Expenses	Time	Active locations	Route(s)
Cost minimization	5000302737	141	1	*i1-14-1-4-12-11-13-6-2-16-7-3-17-15-10-19-8-5-9-20-18-i1*
Time minimization	5.95003E+10	14	1-8	*i1-19-1-16-17-18-i1* *i2-11-i2* *i3-14-i3* *i4-15-7-4-i4* *i5-20-5-3-i5* *i6-6-10-i6* *i7-12-9-8-i7* *i8-13-2-i8*

In order to obtain the maximum value of each objective, every objective is optimized separately. The results have been presented in Table 2.

Table 2. Results of single-objective maximization on the case study

	Expenses	Time	Active locations	Route(s)
Cost maximization	59500464860	40	1-8	*i1-3-7-13-i1* *i2-9-8-6-19-1-10-i2* *i3-18-i3* *i4-11-i4* *i5-14-i5* *i6-20-16-i6* *i7-2-17-12-i7* *i8-5-4-15-i8*
Time maximization	5000302637	141	1	*i1-14-1-4-12-11-13-6-2-16-7-3-17-15-10-19-8-5-9-20-18-i1*

Considering the minimum and maximum values achieved for objective functions of case study, the goals and other parameters of GP are set as follows:

$Cost^{\max} = 59500464860$

$Cost^{\min} = 5000302737$

$g_{cost} = 5000302737$

$T^{\max} = 141$

$T^{\min} = 14$

$g_T = 14$

$w_1 = w_2 = 0.5$

The results of solving Model (28) are presented in Table 3. As shown in Table 3, there are 6 routes and 6 active depots. The overall expenses are 42 billion, which is different from its goal value. On the other hand, the maximum time of routes is 19, which is close to its ideal value (14).

Table 3. Results of GP on the case study with 20 nodes and 8 depots

Expenses (Billion)	Time	Active locations	Route(s)
42	19	1,3,4,6,7,8	*i1-19-14-17-2-18-i1* *i3-12-20-i3* *i4-15-13-3-i4* *i6-1-8-11-i6* *i7-7-10-5-i7* *i8-4-9-16-6-i8*

On the other hand, the proposed GP can provide a qualified and compromise solution considering the goals of both objective function.

4-4- Sensitivity Analysis on Parameters of Proposed Model

In this sub-section the sensitivity analysis of parameters of proposed model is presented. One of the most important parameters in sensitivity analysis is the value of goals. So, the sensitivity analysis is accomplished based on the value of goals. Table 4 shows the results of this analysis.

Table 4. Results of sensitivity analysis of goal values

First goal (Billion)	Second goal (Hour)	Expenses (Billion)	Time	Active locations	Route(s)
12	50	11	61	1,7	i1 8 17 19 20 4 9 16 6 2 18 i1 i7 7 12 15 13 3 11 5 14 1 10 i7
12	61	11	61	1,7	i1 19 20 15 7 12 4 9 16 6 2 i1 i7 13 3 11 5 14 1 8 17 10 18 i7
8	100	6	124	7	i7 7 12 4 15 13 3 11 5 20 9 10 18 16 17 19 14 1 8 6 2 i7
5.5	120	5	126	1	i1 19 11 5 20 15 7 13 3 14 1 18 16 6 2 12 4 9 8 17 10 i1
17	50	16.5	50	1,2,7	i119 14 7 15 13 3 9 2i1 i116 4 5 1 12 11i1 i7 10 6 18 20 8 17 i7
31	30	29.5	30	1,2,3,7,8	i1 18 4 11 i1 i2 20 5 14 1 19 i2 i3 9 2 15 7 i3 i7 13 3 8 17 10 i7 i8 12 16 6 i8

It is notable that in the third column of Table 4 the estimation of cost does not include the routing cost. It can be concluded form Table 4 that locations 1, and 7 are activated in the most cases. So, these two locations are reliable and robust. These locations can be assumed as suitable choice in presence of variability of goals. Moreover, it can be seen that the routing of a unique location is different as the goals changes.

Another important parameter is fixed location cost. So, the sensitivity of results against fixed location cost of candidate facilities is accomplished and the results are presented in Table5. The objective cost includes fixed location cost, and construction cost. The values of first and second goals are set as 12 billion and 50 hours, respectively.

Table 5. Results of sensitivity analysis of fixed location cost candidate facilities

Cost of location 1	Cost of location 7	Total cost (Billion)	Routing cost (Billion)	Time	Active locations	Route 1	Route 2
4	6	10	0.299	61	1,7	i1 19 11 5 3 20 4 9 16 17 10 i1	i7 12 15 7 13 14 1 8 6 2 18 7 i7
5	6	11	0.298	61	1,7	i1 19 11 5 3 14 1 18 16 17 10 i1	i7 7 13 20 4 15 12 9 8 6 2 i7
6	6	11.5	0.314	62	2,7	I2 18 16 17 19 5 14 1 8 6 2 i2	i7 7 13 3 11 20 15 12 4 9 10 i7
4	5	9	0.256	61	1,7	i1 19 11 14 1 18 16 17 8 6 2 i1	i7 7 13 3 5 20 4 15 12 9 10 i7
5	5	10	0.281	61	1,7	i1 8 17 19 5 20 9 18 16 6 2 i1	i7 7 12 4 15 13 3 11 14 1 10 i7
6	5	11	0.256	61	1,7	i1 19 11 14 1 8 17 16 6 2 18 i1	i7 13 3 5 20 4 15 7 12 9 10 i7
4	7	11	0.284	61	1,7	i1 19 5 20 9 8 17 10 16 6 2 i1	i7 12 4 15 7 13 3 11 14 1 18 i7
5	7	11	0.321	63	1,8	i1 10 16 1 19 5 14 7 12 9 18 i1	i8 17 8 6 2 20 4 15 13 3 11 i8
6	7	11.5	0.301	63	1,2	i1 8 6 1 19 11 5 3 14 2 18 i1	i2 13 20 15 7 12 4 9 16 17 10 i2

As can be concluded from contents of Table 5, the active locations are changes due to change in fixed location cost of candidate facilities. Although in some case no change is seen in the active locations while the optimum routing plans are changed.

It can be concluded form Table 5 that the locations 1, and 7 are the most selected locations. These two locations are almost selected under all scenarios for costs.

4-5- Obtained results versus practical experiences

As mentioned in this study, the aim is to select potential locations for the establishment of post offices and to optimize the routing of vehicles of these established offices in order to offer suitable services to customers. Based on the values obtained by the proposed model of this study and the current practical values of Tehran post Office, a comparison is made. This comparison has been shown in Table 4.

Table 4. Results of proposed model VS practical results

	Active locations	Number of active routes	Expenses (billion Tomans)	Time of trip (hour)
Practical experience	1,2,3,4,5,6,7,8	17	73	28
Proposed model	1,3,4,6,7,8	6	42	19

The data collected from Tehran Post Office show that there 8 active post centers in Tehran. Also, there are approximately 17 routes. The expenses of transportation, locations, and time of trip have been given in Table 4. Based on the results obtained from the solution of the proposed model of this study, only 6 centers and 6 routes were active. A comparison between these two sets of data shows thatthe proposed model of this study can significantly reduce both expenses and time of trips. In fact, the results obtained in this research can help us to improve the current situation of Tehran Post Office system to a significant extent.

5- Conclusion and future research direction

In this study a new type of bi-objective location-routing problem was developed and customized for post office location and routing problem. In the proposed problem, the aim was to locate the post office sites and to optimize routing of vehicles transferring the post parcels to customers. The main objectives were total cost of the system and the trip time. Several logical and practical constraints due to nature of post offices and transportation fleets were also considered in the problem. The problem was modeled using a bi-objective mixed-integer mathematical programming. A solution procedure based on goal programming was proposed to handle the model.

The proposed model was applied on a real case study in Tehran's post offices wherein there were 20 demand points and 8 candidate site locations in order to establish post offices. The demand points were estimated based on geographical information system and requests received in the past 12 months. The model was applied on case study and the results were compared with existing practical experiences. Sensitivity analysis on main parameters of proposed models was accomplished and the results were analyzed. The proposed model showed a considerable reduction in both total cost of the system and trip time of delivery of parcels to customers. The proposed model can be used in order to reduce cost and improve the level of service to customers. The main points and achievement of this study can be summarized as follows:

- Customizing location-routing problem for locating post offices and delivery of post parcels
- Developing abi-objective mathematical programming model for the problem
- Solving the associated problem using weighted goal programming approach
- Applying the model and solution methodology in a real case study
- Employing a sensitivity analysis on parameters of proposed model and comparing the results with those of experimental procedure

Some suggestions can be made for future researches. The location-routing problem of this study was a combination of the two problems of locating and routing. Location problem is a strategic problem. The period of decision-making for this problem is between 5 and 20 years. On the other hand, routing problems are operational problems. In these problems, decisions are made on a daily basis. In multi-periodic form of the problem, combining the expenses related to locations over a long period of time and routing costs during the associated period of time is more logical and produces better results.

The proposed model of this study can be customized and used in other similar systems such as electricity production-distribution, water resource management systems, pharmaceutical distribution systems during crisis, blood supply-distribution systems, waste collection networks, and snow removal systems.

In this study, goal programming method was employed in order to generate compromise solution. It is notable that in GP varying goals will lead to different answers. However, the variety among answers cannot easily be recognized. Other multi-objective methods can also be used in order to generate Pareto front of the problem including several non-dominated solutions. In this way, decision-maker can select the preferred answer from among the existing Pareto answers. Heuristic and meta-heuristic methods can be assumed as alternative solutions procedures in large-scale problems.

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