Sigma J Eng Nat Sci, Vol. 40, No. 1, pp. 63-78, March, 2022

Sigma Journal of Engineering and Natural Sciences
Web page info: https://sigma.yildiz.edu.tr
DOI: 10.14744/sigma.2022.00006

Research Article

Comparative solution approach with quadratic and genetic programming to multi-objective healthcare facility location problem

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ARTICLE INFO

Article history
Received: 27 November 2020
Accepted: 14 January 2021

Key words:
Healthcare facility layout problem; Genetic algorithm; Quadratic programming; Quadratic Assignment Problem (QAP); Multi-objective facility layout problem; Hospital layout

ABSTRACT

Facility layout planning is an indispensable part of the manufacturing and service operations. In the literature, there are two main different approaches for the solution of facility layout problem: While the first one aims to minimize both total transportation and assignment costs in a quantitative way, the second one aims to maximize the closeness relationship in a more qualitative way. In this study, we use both of these approaches to model a multi-objective facility layout optimization problem depending on a Quadratic Assignment Problem (QAP) formulation.
We consider three objective which are minimizing the total walking distance, and the maximization of area satisfaction level and closeness relationships. Since these objectives have different scales, we normalize them to prevent a potential domination effect. The n, we solve the problem using Quadratic Assignment Problem (QAP) formulation and a genetic algorithm approach and compare the results. These approaches provide non-dominated solutions to multi-objective problem being considered. In this way, we assign the departments of a healthcare facility to predetermined areas. In addition, our formulation enables the planners to prevent patient losses and increase the patient satisfaction.

Cite this article as: Gulsun B, Mic P, Edalı M. Comparative solution approach with quadratic and genetic programming to multi-objective healthcare facility location problem. Sigma J Eng Nat Sci 2022;40(1):63–78.

INTRODUCTION

Healthcare Facilities (HF) is one of the facility types which provides healthcare services via different departments assigned to previously-constructed available places. According to legal authorities, buildings that provide healthcare services are defined as follows: "Hospitals, nursing homes, child care and rehabilitation centers, dispensaries, and other similar facilities are classified as such. Primary healthcare facilities, private clinics, infirmaries,

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This paper was recommended for publication in revised form by Regional Editor Ferkan Yilmaz

diagnosis and treatment centers, and medical laboratories are also considered as buildings where healthcare services are provided." [1]. In order to be run efficiently and effectively, workflows and layout plans of all industrial facilities should be optimized accordingly. Similarly, as service providers, healthcare facilities should also be organized and designed by considering patient flows among different departments. Layout planning for healthcare facilities is a critical decision because (i) initial investment costs for construction or maintenance cost is generally high, and (ii) it is long-term. Although small modifications to these facilities are possible in the future, the initial facility design is assumed to be used for years. In addition, layout designs have strong effects on daily operations of these facilities; they determine not only the walking distance of patients but also the interaction among different departments [2].

Excess number of patients as well as inappropriate (or suboptimal) layout plans in HF negatively affects the flow inside that facility. As a result, waiting times of patients and walking times among different departments may significantly increase. These might result in increased dissatisfactions among patients and inefficiencies in healthcare operations. Waste, which is defined as all of the non-value adding operations, is one of the main causes resulting inefficiencies and losses in a company. Cost minimization is one of the main criteria considered during layout optimization processes. However, there might be other criteria to be considered as well. The main motivation behind optimum layout planning for HF is to reduce the walking times and distances as well as minimizing the all kind of waste resulting from suboptimal planning. In the literature, there are many different studies concerning about the different aspects of the layout planning of HF. Davies [3] modeled the problems related to HF and emphasized the critical points to be considered for the use of these models. Afshari and Peng [4] presented an overall assessment of the techniques used for layout optimization of HF. They also focused on the questions arising during the optimization processes and suggested answers to those questions. Arnolds and Nickel [5] presented an extensive literature survey on layout problems of HF. Ahmadi-Javid et al. [6] conducted a survey study with ten describing factors to categorize the HF providing emergency and non-emergency care and provided a literature survey depending on this framework. In their study, Butler et al. [7] concluded that both simulation and optimization approaches might be required for hospital layout planning by considering the multi-level nature of the policies.

There are also other studies having a more focused framework utilizing a diverse set of algorithms for HF layout planning. Our literature survey shows that the most frequently used approach is mathematical modeling. Syam and Cote [8] developed a framework to mathematically analyze the issues related to specialized healthcare facilities. By using simulated annealing algorithm, they solved an optimization problem in which both provided service level and service costs are considered as main objectives. Aguiar and Mota [9] focused on HF location problems with the help of p-median, set covering, and p-center models. Dong-Guen Kim and Yeong-Dae Kim [10] developed an integer programming model to maximize the number of patients under budget constraints in the context of layout planning and solved it via a Lagrangean relaxation-based heuristic. Toro-Diaz et al. [11] integrated an integer programming model with queuing elements and a hypercube model representing congestion for the optimization of layout and shipment decisions. An et al. [12] integrated disruption risks, traffic intensity, and queue delays inside the facility with a scenario-based stochastic facility layout problem. Mestre et al. [13] proposed two layout and assignment models to reorganize the hospital network system via minimizing costs and improving geographical accessibility. Gai and Ji [14] developed a linear programming formulation, which enables the analyst to get a set of layout alternatives, to minimize transportation costs by incorporating both quantitative and qualitative factors. They further proposed a novel and multi-attribute group decision-making approach to obtain a quantitative ranking of the layout alternatives. In the literature, some other approaches used to solve HF layout problems including simulation modeling [15], discrete-event simulation [16–18], and ant colony algorithm [19].

Multi-objective modeling, which can be considered as another family of approaches frequently used for HF layout optimization, includes a bi-objective modeling study with efficiency and covering-oriented objectives [20], an enhanced version of the cost-oriented p-median location and assignment problem [21], and a four-objective model dealing with the minimization of inequality in access to healthcare service, construction costs, the number of people cannot be covered by at least one HF, and the maximization of access to healthcare services for the whole population [22]. Other studies include a systematic layout planning model [23], a capacitated maximum coverage layout model [24], a sequential pattern mining approach for determining critical paths for clinics [25], simulation modeling for capacity planning in intensive care units [26], a hybrid multi-criteria decision-making model for selecting landfill areas for wastes produced by HF in a sustainable way [27]. After introduced by Koopmans and Beckmann [28] in 1957 as a facility layout modeling technique, Quadratic Assignment Problem (QAP) has been frequently used for facility layout problem modeling [29–31] as well as for HF layout planning [32–35]. Some of these studies are concerned with the minimization of annual flow and pairwise distance between facilities [32], while others aim to minimize mean walking time [33] or total travel time [34]. During the literature survey, we were not able to find a study which aims to optimize two or more objectives which are previously mentioned, or a study aiming to compare several approaches.

Layout problems are not typical; each problem has its own set of assumptions, constants, and constraints. Therefore, there is no single solution method fits well to all of these problems. In addition, each problem should be modeled realistically rather than fitting the problem to previously developed models. In this respect, the main aim and contribution of this study is to model the problem of locating the departments of a healthcare facility as a Quadratic Assignment Problem, which considers seven different strategies including hybrid ones, and to solve it with an exact method and a genetic algorithm in a comparative manner. Then, the approach is used to locate the departments of a healthcare facility to obtain a better layout, and the results are discussed.

The remainder of this paper is structured as follows: Section 2 provides the methodology, which includes the mathematical model, related strategies, and solution strategies. Section 3 presents an application of the proposed methodology and provides the numerical results. Section 4 summarizes the main findings and possible future studies.

METHODOLOGY

In this study, we aim to assign a set of HF departments to available spaces according to a set of criteria. In order to determine these criteria, we interviewed healthcare professionals (i.e., service providers) and patients (i.e., service recipients). As a result, we categorize the expectations and requests under three main points: (i) departments with high patient demand should be assigned to larger spaces, (ii) walking distances of patients among the departments should be minimized, and (iii) departments with higher relationship in between should be assigned to closer spaces. These three main expectations and requests will be considered during the assignment of departments. These objectives are explained in detail as follows:

1. The area expectation of each department (d), which reflects the expectations of medical doctors, should be satisfied. This objective will be satisfied by assigning highly-demanded departments (with a demand value S) to larger available areas.
2. This objective will be satisfied by assigning the departments to the available areas (A) so that the walking distances among the departments (F) as well as the total walking distance of the patients (M) will be minimized. This is a requirement imposed by both patients and medical doctors. While transportation cost is a significant factor in a manufacturing facility, the same is not valid for a HF. Therefore, the term "transportation" can be attributed to the movement of patients in a HF.
3. The departments having high-level interrelations (R) should be located close to each other so that relationship value (RV) is increased. This objective is the expectation of both patients and medical doctors.

These abovementioned objectives should be satisfied at the same time. In this respect, we restate these three objectives: O_1 (1st Objective): Area satisfaction level; departments with high level of patient demand should be assigned to larger areas, and the total area satisfaction level should be maximized. O_2 (2nd Objective): Walking distance; total walking distance of patients should be minimized since the lower this objective is the higher the satisfaction level is. O_3 (3rd Objective): Closeness relationship satisfaction level; departments should be assigned to available spaces so that the total closeness relationship is maximized.

These three objectives, which are conflicting in nature and having different scales, should be satisfied simultaneously while preventing them to suppress each other. In other words, the values of these three objectives should be comparable. Therefore, in this study, we use "percent normalization" [36].

Building the Model

The assumptions taken into account while creating a mathematical model for our problem are as follows:

- Each department can only be assigned to one rea,
- There can be only one department in each area,
- Decision variables are binary,
- The distances between departments are rectilinear.

The developed mathematical model and utilized indices, parameters and decision variables are as follows:

$$X_{ij} = \begin{cases} 1 & \textit{if department i is assigned to area j} \\ 0 & \textit{otherwise} \end{cases}$$

The decision variables are binary ($X_{ij} \in \{0,1\}$).

The parameters of the model are indicated below:

i,k	=	Departments, $N = \{1,2,\ldots,i,\ldots,k,..,n\}$
j,l	=	Areas, $N = \{1,2,\ldots,j,\ldots,l,..,n\}$
P	=	Strategies, $P = \{1,2,\ldots,s,..,p\}$
d_i	=	Area expectation of department i,
S_i	=	Number of patients admitting to department i,
A_j	=	Numerical (area) value of area (m^2),
TD_i	=	Area satisfaction level of department i,
D_{jl}	=	Rectilinear distance between the centers of areas j and l (meter),
SM_{ij}	=	Area assignment value of department i in area j,
F_{ik}	=	Patient flow from department i to department k,
R_{ik}	=	Relationship value between department i and department k,
O_1, O_2, O_3	=	Objectives,
g_1, g_2, g_3	=	Normalized objective values,
a_{ij}	=	Normalized area assignment value of department i in area j,

b_{ijkl} = Normalized transportation value from department i in area j to department k in area l,

c_{ijkl} = Normalized closeness value between department i in area j and department k in area l,

M_{ijkl} = Walking distance from department i in area j to department k in area l,

$M_{ijkl}(s)$ = Total walking distance among the assigned departments for strategy s,

RV_{ijkl} = Closeness relationship value between department i in area j and department k in area i,

$RV_{ijkl}(s)$ = Total closeness relationship value among the assigned departments for strategy s,

$TDO(s)$ = Average satisfaction level for strategy s,

$maxM$ = $\max(M_{ijkl})$,

$maxRV$ = $\max|RVijkl|$,

$maxSM$ = $\max(SM_{ij})$,

Z = Total objective function value,

w_1, w_2, w_3 = Weights.

MATHEMATICAL MODEL

Objective Function

O_1, O_2, O_3 should be optimized as shown in Eq. (1).

$$optZ = O_1 + O_2 + O_3 \tag{1}$$

$$O_1 = Max\,Z_1' \quad = \sum_{i=1}^{n}\sum_{j=1}^{n} SM_{ij}X_{ij} \tag{2}$$

$$O_2 = Min\,Z_2' \quad = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} M_{ijkl}X_{ij}X_{kl} \tag{3}$$

$$O_3 = Max\,Z_3' \quad = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} RV_{ijkl}X_{ij}X_{kl} \tag{4}$$

$$optZ = Max\,Z_1' + Min\,Z_2' + Max\,Z_3' \tag{5}$$

$$MinZ = Min\,Z_1 + Min\,Z_2 + Min\,Z_3 \tag{6}$$

Here, Eq. (1), optimizes the sum of the objectives, and Eq. (2) maximizes the sum of area assignment values. Eq. (3) minimizes the total walking distance between department i assigned to area j and department k assigned to area l. Eq. (4) maximizes the sum of the closeness relationship values between department i assigned to area j and department k assigned to area l. Eq. (5) optimizes the sum of Eq. (2)–(4). Objectives having different scales in Eq. (5) are normalized in Eq. (6).

$Max\,Z_1$ is related to assigning departments with high level of patient demand to larger areas as much as possible. In this direction, Eq. (7) - Eq. (9) can be formulated as follows:

$$SM_{ij} \;=\; S_iA_j \tag{7}$$

$$a_{ij} \;=\; \left(\frac{SM_{ij}}{\max SM}\right) \tag{8}$$

$$MinZ_1 \;=\; \sum_{i=1}^{n}\sum_{j=1}^{n} W_1\left(1-a_{ij}\right)X_{ij} \tag{9}$$

Here, Eq. (7) is the "assignment value", and it equals to the multiplication of the patient demand of department i and the area of j. Eq. (8) is the normalized value of the "assignment value". In the equation, all SM_{ij} values are normalized by dividing them to max SM. Eq. (9) transforms the first objective so that it can be considered as a minimization problem. This is achieved by multiplying the decision variables by $(1 - a_{ij})$ instead of a_{ij}. In the equation, w_1 represents the weight given to the first objective.

$Min\ Z_2$ aims to minimize the total walking distance of patients by assigning departments which have large volumes of patient flow in between as close as possible. Equations related to this objective, Eq. (10) - Eq. (12), are defined as follows:

$$M_{ijkl} \;=\; F_{ik}D_{jl} \tag{10}$$

$$b_{ijkl} \;=\; \left(\frac{M_{ijkl}}{maxM}\right) \tag{11}$$

$$MinZ_2 \;=\; \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} w_2 b_{ijkl}X_{ij}X_{kl} \tag{12}$$

Eq. (10), M_{ijkl}, is the walking distance of patients from department i in area j to department k in area l. Eq. (11) normalizes the M_{ijkl} values while Eq. (12) aims to minimize the second objective in the problem by considering weight w_2.

$Min\ Z_3$ aims to maximize the closeness of the departments that have high relationship in between. To transform this objective to a minimization form, we set the closeness relationship values (R_{ik}) in an increasing order. As it can be seen in Table 6, the highest relationship, A, is given the weight of 1 while the lowest relationship, U, is given the weight of 10. In this way, one can consider the maximization of the closeness relationships in a minimization context.

$$RV_{ijkl} \;=\; R_{ik}D_{jl} \tag{13}$$

$$c_{ijkl} \;=\; \left(\frac{RV_{ijkl}}{maxRV}\right) \tag{14}$$

$$MinZ_3 \;=\; \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} w_3 c_{ijkl}X_{ij}X_{kl} \tag{15}$$

In the equations given above, Eq. (13), shows the relationship value between department i in area j to department k in area l. In Eq. (14), we normalize all RV_{ijkl} values by dividing them by $MaxRV$. Eq. (15) aims to minimize the quantity calculated in Eq. (14) by considering weight w_3. In Eq. (12) and Eq. (15), there are binary variables to be multiplied and these can be linearized. However, since the software used to solve such problems automatically linearizes nonlinear structures, we did not do any additional linearization in this study.

To take into consideration different strategies, we multiply all the three objectives by weights w_1, w_2 and w_3, respectively. Strategy generation is explained in detail in "2.2. Strategy Development". Considering the explanations given above, we can express Eq. (6) after these explanations given above as follows:

$$\begin{aligned} MinZ \;=\; & \sum\nolimits_{i=1}^{n}\sum\nolimits_{j=1}^{n} w_1\left(1-a_{ij}\right)X_{ij} \\ & + \sum\nolimits_{i=1}^{n}\sum\nolimits_{j=1}^{n}\sum\nolimits_{k=1}^{n}\sum\nolimits_{l=1}^{n} w_2 b_{ijkl} X_{ij} X_{kl} \\ & + \sum\nolimits_{i=1}^{n}\sum\nolimits_{j=1}^{n}\sum\nolimits_{k=1}^{n}\sum\nolimits_{l=1}^{n} w_3 c_{ijkl} X_{ij} X_{kl} \end{aligned} \tag{16}$$

S.t.

$$\sum\nolimits_{i=1}^{n} X_{ij} = 1 \quad \forall j \tag{17}$$

$$\begin{aligned} & \sum\nolimits_{j=1}^{n} X_{ij} = 1 \quad \forall i \\ & X_{ij} \in \{0,1\}, \quad \forall i,j \end{aligned} \tag{19}$$

Eq. (16) is the final version of Eq. (6) whose details are given in Eq. (9), (12), and (15). Eq. (17) and Eq. (18) ensure that each department can only be assigned to one area, and vice versa. According to the literature; the problem we aim to solve in this paper is a multi-objective, constrained, and binary Quadratic Assignment Problem (QAP) [37]. For the solution of these kind of problems, exact methods or metaheuristic methods can be utilized as in literature; thus, we use both an exact and a heuristic method (specifically, a genetic algorithm [38]) to solve the addressed problem. The genetic algorithm is coded in R programming language [39], and the exact method is in implemented in GAMS [40] and WinQSB2.0 Quadratic Programing (QP) module [41].

Strategy Development

In this study, we generate seven different st*rategies by assigning values to each weight (i.e., w_1, w_2, w_3) so that $w_1 + w_2 + w_3 = 1$ and w_1, w_2, w_3 ∈ [0,1]. These different strategies enable us to observe how the three main objective changes with respect to different values of these weights. In this way, we aim to find solutions that satisfy all the objectives. These seven strategies can be described as follows:*

Strategy 1: All the objectives have the same weight (i.e., $w_1 = w_2 = w_3 = 1/3$).

Strategy 2: We give the highest priority to area satisfaction level. In this strategy, departments with high level of patient demand should be assigned to larger areas ($w_1 = 1$, $w_2 = w_3 = 0$).

Strategy 3: We give the highest priority to the minimization of total walking distance of patients ($w_2 = 1$, $w_1 = w_3 = 0$).

Strategy 4: We give the highest weight to the maximization of total closeness relationship ($w_3 = 1$, $w_1 = w_2 = 0$).

In Strategy 5, 6, and 7, all the weights are greater than zero to create "hybrid" strategies. These hybrid strategies can be defined as follows:

Strategy 5: In this strategy, the priority of the first objective (area satisfaction level) is two times higher than the priority of the second (total walking distance) and third (closeness relationship satisfaction level) objectives ($w_1 = 0.50$; $w_2 = 0.25$; $w_3 = 0.25$).

Strategy 6: In this strategy, the priority of the second objective (total walking distance) is two times higher than the priority of the first (area satisfaction level) and third (closeness relationship satisfaction level) objectives ($w_1 = 0.25$; $w_2 = 0.50$; $w_3 = 0.25$).

Strategy 7: In this strategy, the priority of the third objective (closeness relationship satisfaction level) is two times higher than the priority of the first (area satisfaction level) and second objectives ($w_1 = 0.25$; $w_2 = 0.25$; $w_3 = 0.50$).

Solution Procedure of the Problem

The solution procedure of the problem is as follows:

Step 1 : Pick one of the strategies in a consecutive order ($P = \{1,2,\ldots,7\}$),

Step 2 : Follow the steps given below to solve the problem:

i. Consider the mathematical model given in Eq. (16), (17), and (18),

ii. Solve the problem by using GAMS and WinQSB2.0 QP for exact solution,

iii. Solve the problem by using a genetic algorithm coded in R programming language.

iv. If all the strategies are evaluated, go to Step 3, otherwise go to Step 1.

Step 3 : For $\forall X_{ij}$, calculate O_1, O_2 ve O_3 by following the steps given below;

i. For O_1 and $\forall X_{ij}$, calculate TD_i as follows:

$$\text{If } A_j / d_i < 1, \quad TD_i = A_j / d_i \tag{19}$$

$$\text{else} \quad TD_i = 1 \tag{20}$$

For strategy s, calculate the average satisfaction level using Eq. (21).

$$TDO(s) \;=\; \sum\nolimits_{i=1}^{n}\left(TD_i\right)/n \qquad i=1,2,\ldots.n \tag{21}$$

ii. For O_2 and $\forall X_{ij}$, calculate the walking distance of patients between departments assigned to areas by Eq. (10). Then, for strategy s, calculate the total walking distance of patients between departments assigned to areas by Eq. (22).

$$M_{ijkl}(P) \;=\; \sum\nolimits_{i=1}^{n}\sum\nolimits_{j=1}^{n}\sum\nolimits_{k=1}^{n}\sum\nolimits_{l=1}^{n} M_{ijkl} \tag{22}$$

iii. For O_3 and $\forall X_{ij}$,, calculate the relationship values between assigned departments by Eq. (13). Then, for strategy s, calculate the total relationship value by Eq. (23).

$$RV_{ijkl}(s) \;=\; \sum\nolimits_{i=1}^{n}\sum\nolimits_{j=1}^{n}\sum\nolimits_{k=1}^{n}\sum\nolimits_{l=1}^{n} RV_{ijkl} \tag{23}$$

Normalization:

Step 4 : For each strategy s, normalize O_1, O_2 and O_3, which are calculated at Step 3, as follows:

i. g_1 : Normalized area satisfaction level; the closer the value of g_1 to 1 is, the more satisfied this objective is. Among all strategies, determine max$TDO(s)$ and, for strategy s, calculate g_1 using Eq. (24):

$$g_1 \;=\; TDO(s)/\max TDO(s) \tag{24}$$

ii. g_2 : Normalized total walking distance of patients; the closer the value of g_2 to 1 is, the more satisfied this objective is. Among all strategies, determine min M_{ijkl} (s) and, for strategy s, calculate g_2 using Eq. (25):

$$g_2 \;=\; \min M_{ijkl}(s)/M_{ijkl}(s) \tag{25}$$

iii. g_3 : Normalized closeness relationship satisfaction level; the closer the value of g_3 to 1 is, the more satisfied this objective is. Among all strategies, determine minRV_{ijkl} (s), and for strategy s, calculate g_3 using Eq. (26):

$$g_3 \;=\; \min RV_{ijkl}(s)/RV_{ijkl}(s) \tag{26}$$

Step 5 : In this step, for each strategy, calculate g_1, g_2, g_3 and their mean, standard deviation, and maximum and minimum values. These mean values stand for the average satisfaction level of each strategy. Standard deviations show how each stategy is "balanced".

Genetic Algorithm

Genetic Algorithm (GA) is a population-based metaheuristic method developed by Holland and inspired by evolutionary theory of Darwin [42]. Meta-heuristic algorithms help to find approximate solutions within a reasonable time to complex and large-scale problems which cannot figured out in a reasonable time by exact algorithms [43]. Since QAP is an NP-hard problem [44], it is more advantageous to solve this problem by meta-heuristic algorithms compared to exact solution methods.

First step of a genetic algorithm is to form the random population in which each individual stands for a solution of the problem. Individuals carry the solution of the problem in their genes in a coded form, and the objective function value of this solution expresses the fitness of the individual in the population. At each iteration, individuals with high fitness are chosen randomly from the population as parents. Parents transfer the solutions coded in their genes to new individuals by crossbreeding. Finally, individuals with a low fitness, in other words the solutions which deliver the worst solutions to the present problem are excluded from the population and new individuals are added instead. This process is repeated along iterations and thus, keeping the individuals in the population which perform best solutions to the problem [43].

In this study, a population of 1000 randomly created individuals is utilized. Each individual carries the information of which hospital department is assigned to which area, and its fitness value is the objective value of QAP. 10 individuals with best fitness values (this corresponds to the individuals with minimum objective function values) are chosen at each iteration and crossbred to generate 10 new individuals. New individuals are then mutated with 20% probability to increase the variety in the population. Finally, these 10 new individuals are replaced with 10 individuals in the population which have the worst fitness values (this corresponds to the individuals with maximum objective function values). This process is repeated for 200 iterations, but the process is terminated if the best fitness value in the population does not improve at the last 50 iterations.

RESULTS AND DISCUSSION

We implemented a case study for the better understanding of our work. In the case study, the facility has 12 departments (outpatient clinics). Demand of departments are given in Table 1 where i stands for existing departments

Table 1. Existing departments with their clarifications, notations and annual expected patient demand of each department

The Clarification of Departments (*i*)	Notation in the Study	Patient Demand S_i
Internal Diseases	A	722
Cardiology	B	394
Pulmonology	C	434
Dermatology	D	450
Psychiatry	E	366
Neurology	F	648
General Surgery	G	474
Neurosurgery	H	492
Plastic Surgery	I	452
Orthopedics	J	552
Urology	K	248
Ear, Nose and Throat	L	444

and S_i stands for annual estimated patient demand of each department. Table 2 and 3 show existent areas in the facility (j) and square meters of these areas and area expectations of existing departments, respectively. Number of patients flowing among departments are partially taken from [45] and presented in Table 5. Other required data for each of three objectives are demonstrated under their titles.

We need to maximize the following objectives to ensure a general improvement in the facility layout.

In order to have a maximum value in area assignment (G_1), we will use the information provided in Table 3. Table 3 demonstrates space expectations according to existing departments' demands. To ensure that departments with high demand are assigned to larger available spaces, demand of each department and numerical area values of each existing space are multiplied (see Eq. (7)). Then, these values are normalized by dividing all of them by the largest value and converted to minimization form in accordance with objective equation. Final results are given in Table 4.

Table 2. Existing spaces and their square meters

	Areas (j)											
	1	2	3	4	5	6	7	8	9	10	11	12
Area (A_j)	336	72	192	180	72	72	84	36	36	36	36	36

Table 3. Space expectations according to existing departments' demands

Departments (*i*)	A	F	J	H	G	I	D	L	C	B	E	K
Patient Demand (S_i)	722	648	552	492	474	452	450	444	434	394	366	248
Area No (j)	1	3	4	7	2	5	6	8	9	10	11	12
Area Expectation (d_i)	336	192	180	84	72	72	72	36	36	36	36	36

Table 4. $(1 - a_{ij})$ Matrix which is converted to a minimization form

$(1 - a_{ij})$		1	2	3	4	5	6	7	8	9	10	11	12
		336	72	192	180	72	72	84	36	36	36	36	36
A	722	0.00	0.79	0.43	0.46	0.79	0.79	0.75	0.89	0.89	0.89	0.89	0.89
B	394	0.45	0.88	0.69	0.71	0.88	0.88	0.86	0.94	0.94	0.94	0.94	0.94
C	434	0.40	0.87	0.66	0.68	0.87	0.87	0.85	0.94	0.94	0.94	0.94	0.94
D	450	0.38	0.87	0.64	0.67	0.87	0.87	0.84	0.93	0.93	0.93	0.93	0.93
E	366	0.49	0.89	0.71	0.73	0.89	0.89	0.87	0.95	0.95	0.95	0.95	0.95
F	648	0.10	0.81	0.49	0.52	0.81	0.81	0.78	0.90	0.90	0.90	0.90	0.90
G	474	0.34	0.86	0.62	0.65	0.86	0.86	0.84	0.93	0.93	0.93	0.93	0.93
H	492	0.32	0.85	0.61	0.63	0.85	0.85	0.83	0.93	0.93	0.93	0.93	0.93
I	452	0.37	0.87	0.64	0.66	0.87	0.87	0.84	0.93	0.93	0.93	0.93	0.93
J	552	0.24	0.84	0.56	0.59	0.84	0.84	0.81	0.92	0.92	0.92	0.92	0.92
K	248	0.66	0.93	0.80	0.82	0.93	0.93	0.91	0.96	0.96	0.96	0.96	0.96
L	444	0.39	0.87	0.65	0.67	0.87	0.87	0.85	0.93	0.93	0.93	0.93	0.93

Table 5. Interdepartmental estimated annual patient transfer numbers (F_{ik})

	F_{ik}	A	B	C	D	E	F	G	H	I	J	K	L
A	Internal Diseases	0	100	90	96	32	64	156	0	4	28	84	68
B	Cardiology		0	142	0	48	60	4	4	4	8	4	20
C	Pulmonology			0	6	18	4	38	0	0	56	0	80
D	Dermatology				0	40	4	52	0	164	52	16	20
E	Psychiatry					0	152	0	12	16	16	4	28
F	Neurology						0	8	224	4	44	28	56
G	General Surgery							0	16	36	48	88	28
H	Neurosurgery								0	20	120	8	88
I	Plastic Surgery									0	156	16	32
J	Orthopedics										0	0	24
K	Urology											0	0
L	Ear, Nose and Throat												0
	Total	0	100	232	102	138	284	258	256	248	528	248	444

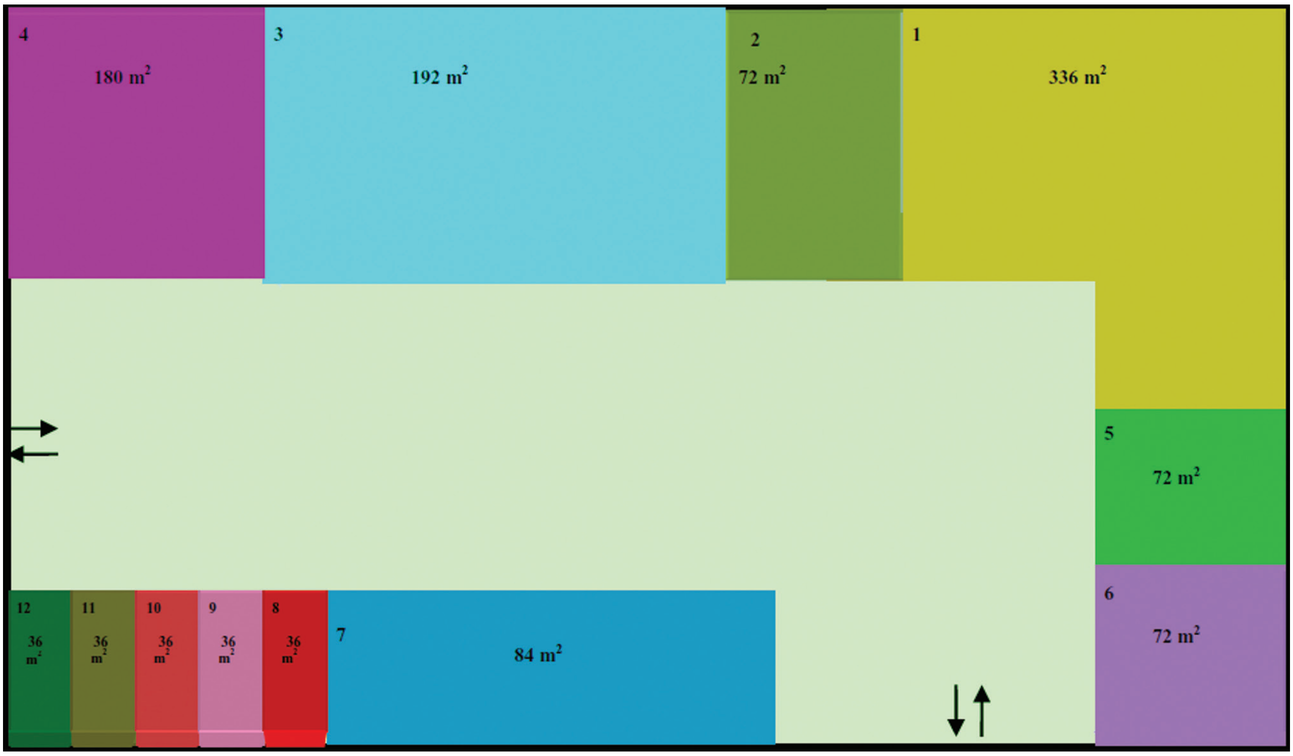

Figure 1. Layout of the healthcare facility.

Table 5 shows estimated patient flows between 12 different departments for a specific period.

Figure 1 shows the layout of the healthcare facility and obtained by reviewing some healthcare facilities in public domain. Areas are right-angled and linear-edged in this study. Distance from an area to another is calculated as the linear distance between the centers of those areas. To have a minimum walking distance (G_2), it is necessary to make the optimum assignment at the layout in Figure 1 using interdepartmental patient flows and the distances between areas. The score of transporting from a department in an area to a department in another area should be minimized. This

Table 6. D_{jl} rectilinear distance among the centers of areas j and l (meter)

	1	2	3	4	5	6	7	8	9	10	11	12
1	0.00	20.00	33.75	47.50	17.50	25.00	40.00	50.00	55.00	60.00	65.00	70.00
2		0.00	16.25	35.00	37.50	45.00	30.00	40.00	45.00	50.00	55.00	60.00
3			0.00	18.75	51.25	58.75	36.25	23.75	28.75	33.75	38.75	43.75
4				0.00	65.00	72.50	50.00	37.50	32.50	27.50	22.50	25.00
5					0.00	7.50	32.50	42.50	47.50	52.50	57.50	62.50
6						0.00	25.00	35.00	40.00	45.00	50.00	55.00
7							0.00	12.50	17.50	22.50	27.50	32.50
8								0.00	5.00	10.00	15.00	20.00
9									0.00	5.00	10.00	15.00
10										0.00	5.00	10.00
11											0.00	5.00
12												0,00

Table 7. Relationship values between departments

Relationship Definition	Relationship Value	Symbol	Patient Number	Interval Value
Too Close	1	A	181	224
Closer	3	E	137	180
Close	5	I	93	136
Far	7	O	49	92
Further	10	U	5	48
Far-off/Never Close	–9	X	0	4

Table 8. Literal relationships between departments (R_{ik})

	Interdepartmental Literal Relationships												Interdepartmental Numerical Relationships											
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**
A		I	O	I	U	O	E	X	U	U	O	O		5	7	5	10	7	3	-9	10	10	7	7
B			E	X	U	O	U	U	U	U	U	U			3	-9	10	7	10	10	10	10	10	10
C				O	U	U	U	X	X	O	X	O				7	10	10	10	-9	-9	7	-9	7
D					U	U	O	X	E	O	U	U					10	10	7	-9	3	7	10	10
E						E	X	U	U	U	U	U						3	-9	10	10	10	10	10
F							U	A	U	U	U	O							10	1	10	10	10	7
G								U	U	O	O	U								10	10	7	7	10
H									U	I	U	O									10	5	10	7
I										E	U	U										3	10	10
J											X	U											-9	10
K												X												-9
L																								

is a success indicator and calculated by Eq. (10). Distance is measured as the rectilinear distance. The rectilinear distance among two points (x_1, y_1), (x_2, y_2) is described as $|x_1 - x_2| + |y_1 - y_2|$ [46]. Table 6 demonstrates the rectilinear distance among the centers of areas j and i.

In the traditional facility layout optimization, one of the well-known methods is to use qualitative relationship information between departments. Then, this qualitative information is transformed to numerical values. Table 7 shows the relationship definitions, corresponding

Table 9. Results of the solution obtained by GA method

	Objective Values Solution Results			Normalized Objective Values				
Strategies (s)	G_1	G_2	G_3	g_1	g_2	g_3	**Mean**	**Standard Deviation**
1	0.818	36,771	3,906	0.818	0.747	0.982	0.849	0.120
2	1.000	42,746	5,508	1.000	0.643	0.696	0.780	0.193
3	0.712	27,482	5,332	0.712	1.000	0.719	0.810	0.164
4	0.779	39,351	3,835	0.779	0.698	1.000	0.826	0.156
5	0.911	40,122	4,194	0.911	0.685	0.914	0.837	0.131
6	0.818	31,297	4,507	0.818	0.878	0.851	0.849	0.030
7	0.829	43,886	3,876	0.829	0.626	0.989	0.815	0.182

Figure 2. Results obtained by GA method.

relationship values and symbols. To calculate the relationship values, we define intervals based on the data given in Table 5. These relationship values are the main inputs of the third objective (G_3). The relationship values between departments assigned to different areas (RV_{ijkl}) are calculated by Eq. (13).

Closeness relationship values depend on the number of patients flowing among departments; departments having large number of patients flows in between must be located close to each other. Interdepartmental total estimated number of patient flows is divided into 6 equal intervals between its maximum value 224 and 0, as presented in Table 5 and interdepartmental relationship values table (Table 7) is generated. In fact, numerical relationship values (see column 2 in Table 7) should be in an increasing order with respect to the importance of the relationship. Since we are dealing with a minimization problem, relationship values in Table 7 are reversed. In other words, lower relationship values show higher relationship importance. Table 5 is converted to the numerical relationships in Table 8 utilizing the relationship values in Table 7.

Solution of the Problem by Genetic Algorithm

For GA solution, for the values of $\forall X_{ij}$ which makes objective function minimum in strategy s; G_1, G_2, G_3 values which are obtained by Step 3 in Section 2.3; normalized g_1, g_2, g_3 values obtained in Step 4; mean and standard deviation values of these are given in Table 9.

Comments of GA solution results in Table 9 are summarized as follows:

- In 1st Strategy and 6th Hybrid Strategy (area satisfaction 50%, walking and closeness satisfaction 25%), the score is 0.849 and this is the highest mean satisfaction score among 7 strategies; but deviation

Table 10. Analysis of the solution of the 6th hybrid strategy by GA method

Departments	Patient Demand (S_i)	Area	Expected Area	Assigned Area No	Realized Area	Satisfaction (TD_i)
A	Internal Diseases	722	336	1	336	1.0
B	Cardiology	394	36	4	180	1.0
C	Pulmonology	434	180	3	192	1.0
D	Dermatology	450	72	6	72	1.0
E	Psychiatry	366	36	9	36	1.0
F	Neurology	648	36	8	36	0.2
G	General Surgery	474	72	2	72	1.0
H	Neurosurgery	492	36	12	36	0.4
I	Plastic Surgery	452	84	7	84	1.0
J	Orthopedics	552	192	10	36	0.2
K	Urology	248	72	5	72	1.0
L	Ear, Nose and Throat	444	36	11	36	1.0

Table 11. Results of the solutions obtained by QAP method

	Objective Values Solution Results			Normalized Objective Values				
Strategies (s)	G_1	G_2	G_3	g_1	g_2	g_3	Mean	Standard Deviation
1	0.770	38,817	4,083	0.770	0.704	0.958	0.811	0.132
2	1.000	40,066	5,538	1.000	0.682	0.733	0.805	0.171
3	0.870	27,338	5,189	0.870	1.000	0.754	0.875	0.123
4	0.804	43,038	4,411	0.804	0.635	0.887	0.775	0.128
5	0.938	37,248	4,609	0.938	0.734	0.849	0.840	0.102
6	0.885	33,870	4,397	0.885	0.807	0.890	0.861	0.046
7	0.787	40,139	3,912	0.787	0.681	1.000	0.823	0.162

in 1st Strategy is high (0.120) and other satisfaction values are low. Since the standard deviation value of 6th Strategy is the lowest (0.030), this strategy ensures a more balanced satisfaction level.

- 2nd Strategy has the value of 1.0 which is the highest value for area satisfaction; with the 0.780 value of mean satisfaction score and the standard deviation is 0.193.
- 3rd Strategy has the value of 1.0 for walking satisfaction while having a score of 0.810 at mean satisfaction. Standard deviation value is 0.164.
- 4th Strategy has the value of 1.0 for closeness relationship score while having a score of 0.826 at mean satisfaction. Standard deviation value is 0.156.

Figure 2 presents the satisfaction values of g_1, g_2, g_3 objectives obtained from Table 9. As seen from Figure, 6th Hybrid Strategy provides a more balanced objective satisfaction. In Figure 2, while variances are high in each strategy; the smoothest distribution is achieved in 6th Hybrid Strategy. 6th Hybrid Strategy's (which results in a good value for the GA solution of the problem) detailed analysis of solution values in Table 9 are presented in Table 10. Mean satisfaction value is 0.818; total walking distance is 31,297 unit and total satisfaction value is 4,507. In this strategy, 9 out of 12 departments (in other words 75% of the departments) are assigned to the area they are expected and are satisfied (1.0), one department is satisfied at a rate of 0.4 and two departments are satisfied at a rate of 0.2. In this strategy, the assignment of each department is detailed in Table 10. For example, Internal Diseases Department with its 722-patient demand is expected to be assigned to an area of 336 m^2 and as a result, it is assigned to an area of 336 m^2. Thus, its realized satisfaction level is 1. While Neurosurgery Department with its 492-patient demand is expected to be assigned an area of 84 m^2, it is assigned to an area of 36 m^2, having a satisfaction level of 0.4. In this strategy; g_1, g_2, and g_3 are resulted in 0.818; 0.878 and 0.851; respectively. Mean satisfaction is 0.849 and standard deviation is 0.03. Thus, it is a balanced satisfaction.

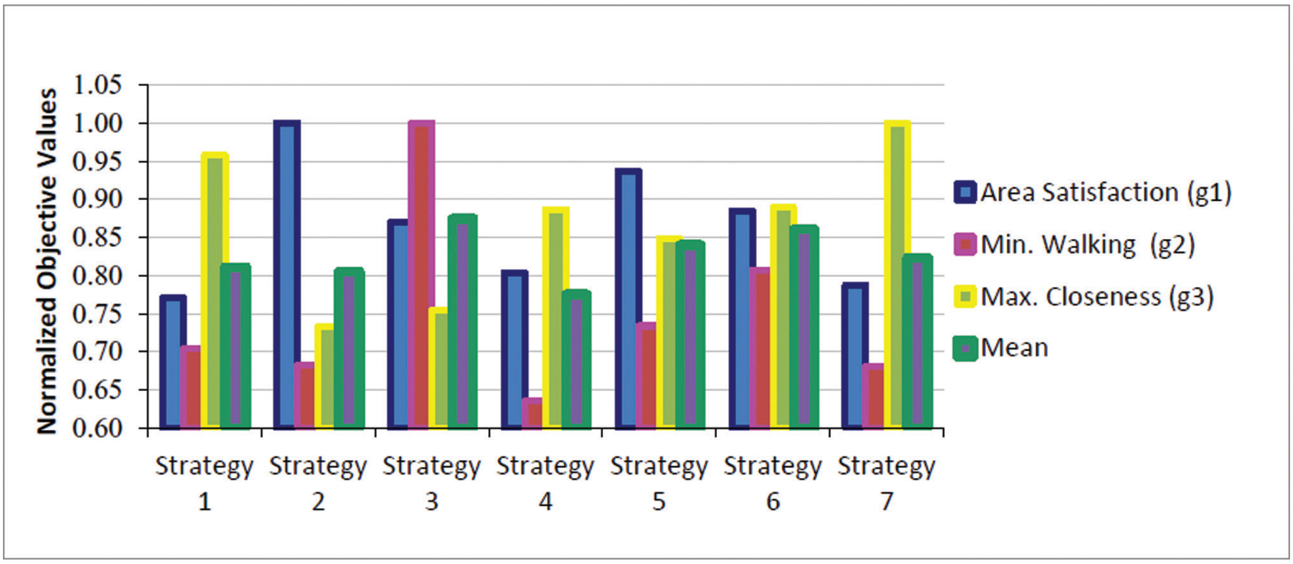

Figure 3. Results obtained by QAP method.

Table 12. Analysis of the solution of the 6.th hybrid strategy obtained by QAP method

Departments	Patient Demand (S_i)	Area	Expected Area	Assigned Area No	Realized Area	Satisfaction (TD_i)
A	Internal Diseases	722	336	1	336	1.0
B	Cardiology	394	36	10	36	1.0
C	Pulmonology	434	180	4	180	1.0
D	Dermatology	450	72	5	72	1.0
E	Psychiatry	366	36	9	36	1.0
F	Neurology	648	36	8	36	0.2
G	General Surgery	474	72	2	72	1.0
H	Neurosurgery	492	36	12	36	0.4
I	Plastic Surgery	452	84	7	84	1.0
J	Orthopedics	552	192	3	192	1.0
K	Urology	248	72	6	72	1.0
L	Ear, Nose and Throat	444	36	11	36	1.0

Solution of the Problem by Exact Model

For QAP, model is solved in GAMS and WinQSB2.0 QP. G_1, G_2, G_3 objective values which are obtained from Step 3 in Section 2.3; normalized g_1, g_2, g_3 objective values obtained from Step 4 and mean and standard deviation values of these are demonstrated in Table 11.

Comments of QAP solution results in Table 11 are summarized as follows:

- In the QAP model solution, mean satisfaction values of the 1st Strategy is 0.811 but standard deviation is comparatively high (0.132), and other satisfaction values are low.
- Area satisfaction of the 2nd Strategy is 1.0; mean satisfaction is 0.805 and its standard deviation is 0.171. Other satisfaction values are low.
- Walking satisfaction of the 3rd Strategy is 1.0; and it also has the highest mean satisfaction score (0.875). However, the standard variation is high for this strategy (0.123), and other satisfaction values are low.
- Closeness relationship score of the 4th Strategy is 1.0. Its mean score is 0.775; and its standard deviation is 0.128.
- About other hybrid strategies, for the approach with 25% area satisfaction, 50% walking satisfaction and 25% closeness satisfaction; mean value is 0.861 and standard deviation is 0.046.

Table 13. Evaluation of GA and QAP model solutions

Solution Method	Strategy	$TDO(s)$	$M_{ijkl}(s)$	$RV_{ijkl}(s)$	g_1	g_2	g_3	Mean	Standard Deviation	Max	Min
GA	1	0.818	36,771	3,906.0	0.818	0.743	0.982	0.848	0.122	0.98	0.74
	2	1.000	42,746	5,508.5	1.000	0.640	0.696	0.779	0.194	1.00	0.64
	3	0.712	27,482	5,332.0	0.712	0.995	0.719	0.809	0.161	0.99	0.71
	4	0.779	39,351	3,835.0	0.779	0.695	1.000	0.825	0.158	1.00	0.69
	5	0.911	40,122	4,194.5	0.911	0.681	0.914	0.835	0.133	0.91	0.68
	6	0.818	31,297	4,507.0	0.818	0.874	0.851	0.847	0.028	0.87	0.82
	7	0.829	43,886	3,876.5	0.829	0.623	0.989	0.814	0.184	0.99	0.62
QAP	1	0.770	38,817	4,083.0	0.770	0.704	0.939	0.805	0.121	0.94	0.70
	2	1.000	40,066	5,338.5	1.000	0.682	0.718	0.800	0.174	1.00	0.68
	3	0.870	27,338	5,189.0	0.870	1.000	0.739	0.870	0.130	1.00	0.74
	4	0.804	43,038	4,411.5	0.804	0.635	0.869	0.769	0.121	0.87	0.64
	5	0.938	37,248	4,609.0	0.938	0.734	0.832	0.835	0.102	0.94	0.73
	6	0.885	33,870	4,397.0	0.885	0.807	0.872	0.855	0.042	0.88	0.81
	7	0.787	40,139	3,912.0	0.787	0.681	0.980	0.816	0.152	0.98	0.68
Mean		0.851	37,341.4	4546,1	0.851	0.750	0.864	0.822			

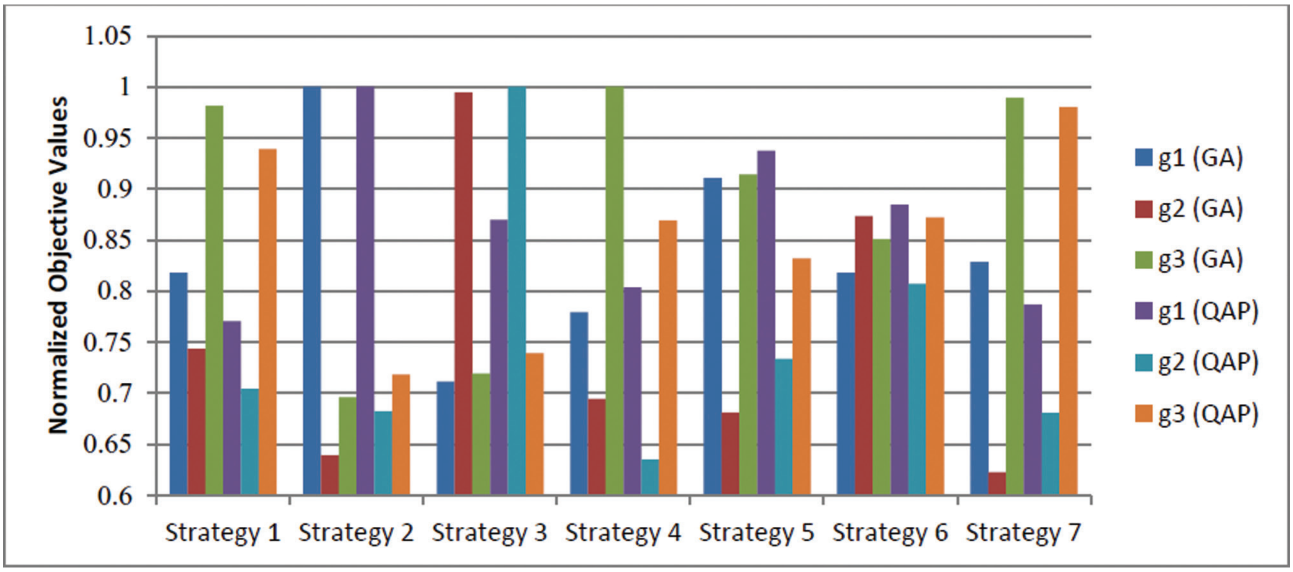

Figure 4. Comparing the results obtained from GA and QAP model solutions.

Figure 3 presents the satisfaction levels of g_1, g_2, g_3 objectives which are obtained from Table 11. 6th Hybrid Strategy provides a more balanced objective satisfaction in this method as well. Objective values of the 6th Hybrid Strategy are given in Table 12 in detail. Table 12 also shows the assignments and satisfaction levels reached by 6th Hybrid Strategy. Here, mean satisfaction value is 0.885; total walking distance is 33,870 unit and total satisfaction level is 4,397.

Table 12 demonstrates which department is assigned to which area according to 6th Strategy. In QAP solution, 10 out of 12 departments (namely, 83.33% of the departments) are assigned to the area they expected and are satisfied (1.0). One department is satisfied at a rate of 0.4 and one department is satisfied at a rate of 0.2. For example, while Internal Diseases Department with its 722-patient demand is expected to be assigned to an area of 336 m^2, this expectation is satisfied with a level of 1.0. While Neurosurgery

Department with its 492-patient demand is expected to be assigned an area of 84 m^2, it is assigned to an area of 36 m^2, having a satisfaction level of 0.4. According to this strategy, g_1, g_2 and g_3 are 0.885; 0.807 and 0.890; respectively. Mean satisfaction is 0.861 and standard deviation is 0.046. Thus, a balanced satisfaction is provided. Table 13 below presents the simultaneous evaluation of GA and QAP model solutions.

Minimum walking-oriented solution of the QAP model ensures the highest mean score (0.870), and standard deviation value is 0.130. However, in the 6th Hybrid Strategy, in which the weight of the objective regarding the walking distance is 50%, the weights of the area satisfaction level and closeness relationship value are 25%, provides a more balanced satisfaction level. In this strategy, the mean and standard deviation of GA are 0.847 and 0.028, respectively. As for QAP model solution, these values are 0.855 and 0.042, respectively. These results indicate that hybrid strategies result better rather than pure (dominant) strategies. In strategies which reducing walking distance is the priority, other satisfaction levels are as low as 0.70. In case of making concessions from walking distance satisfaction, all satisfaction levels reach to a non-dominant levelized satisfaction level.

As demonstrated in Table 13, by comparing the mean satisfaction and standard deviation values obtained from GA and QAP model solutions, it is found that satisfaction values in the 6th Hybrid Strategy are high but standard deviation values are low, yielding a desirable solution. In other strategies, satisfaction values are low but standard deviation values are high, corresponding to an undesirable situation. We can make a general comparison as follows:

- In the 1st Strategy, we obtain a better result for mean satisfaction when we use GA. However, the standard deviation is slightly larger than QAP. In the 2nd Strategy, QAP yields a better result for the mean satisfaction level with a lower standard deviation.
- In the 3rd Strategy, QAP solution returns the best mean satisfaction level with a lower standard deviation.
- Since the 4th Strategy have low satisfaction values and high deviation values in both two solutions, it did not result well.
- 6th Hybrid Strategy results in the highest mean balanced satisfaction level with the minimum deviation values both in GA solution and QAP solution. This shows that all three objectives are satisfied in the same levels.

Figure 4 displays the comparison of satisfaction levels obtained from both GA and QAP problem model solutions for all strategies. As seen from the figure, results acquired from GA and QAP model solutions are similar.

For both solution methods, 6th Hybrid Strategy yields better results and satisfaction values compared to pure strategies. These results show that, as mentioned in Section 2.2 previously (Strategy Development), hybridization technique, which is a widely used productivity enrichment method in genetic engineering, provides an improvement in Health Care allocation as well.

CONCLUSION

This study handled a healthcare allocation problem and according to the results, we can conclude that it is possible to provide a solution to prevent the losses and dissatisfactions which might occur due to the sub-optimal department allocations. In this study, since there are multiple objectives to be achieved simultaneously, we modeled this multi-objective healthcare facility location problem by using a QAP formulation. As the next step, we solved the proposed model by using a GA and an exact solution method.

Although QAP has been utilized for facility layout problems in literature [29-31] and for healthcare facility layout planning [32-35], it is observed that none of these studies address achieving more than two objectives or comparing different approaches, as accomplished in this study. Thus, this study aims to be a valuable contribution to the literature.

For future studies, interdepartmental patient flows can be estimated, and the allocation plan of the healthcare facility can be organized for a longer time horizon based on these estimation values. A simulation model can be utilized to validate the results obtained by the exact and heuristic solutions. In addition, different hybrid strategies can be generated to obtain satisfying solutions. It is also possible to incorporate other specified constrains to the model by interviewing the healthcare facility staff. Thus, allocations which offer more particular solutions to health care facility problems can be revealed. Other different data normalization methods can be utilized, and results can be evaluated. Other weight determination methods might be used, and various strategies with various weight values can be created as well. Furthermore, different available metaheuristic methods in literature such as simulated annealing, tabu search and particle swarm optimization can be applied.

Another long-term suggestion is about the new outpatient clinics which will be set up in the existing facility in the following years. Estimating the patient flows between these new outpatient clinics and other existing ones and conducting an optimization study according to these estimations might be beneficial for the long-term allocation of the facility. In addition, this problem and its modeling can be adapted to multi-floor healthcare problems.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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