

Layout Optimization in a Fitness Industry: An Application of QAP Formulation and Heuristic Approaches

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Abstract: The Quadratic Assignment Problem (QAP) is the problem of determining a one-to-one and onto assignment between two sets, each consisting of n objects (e.g., n facilities and n locations) so as to minimize the sum of the distance \times flow associated with pairs of assignments. In this study, QAP formulation is applied to a fitness center to assign the sports equipment to the related locations on the layout. Facilities are considered as sports equipment and locations are considered the required area for equipment on the layout. A case study with 19 sports equipment is considered. The objective of the study is to allocate the equipment to the 19 available locations to minimize the total walking distance while considering the interactions between sports equipment. An Integer Programming (IP) formulation is applied using GUROBI package program. 2-opt and tabu search algorithms are also applied to find the feasible/optimal solutions in a reasonable time. The results show that the heuristic approaches are more effective than IP in terms of computational time. The optimal result which is obtained by IP, 2-opt and tabu search provides a better layout with 55.47% less distance \times flow compared to the current layout.

Keywords: 2-opt, Fitness Center, Integer Programming, Layout Optimization, Quadratic Assignment Problem, Tabu Search

Introduction

There are several studies in literature that consider the effective and efficient solutions for the real life problems. One of them deals with the green inventory routing and aims to minimize of total cost by application of augmented Tabu Search algorithm (Alinaghian *et al.*, 2021). Another study in that concern focuses on the waste collection via multi-trip capacitated arc routing problem and solution is proposed by utilizing the improved Max-Min Ant System (Tirkolae *et al.*, 2019a). In addition, (Tirkolae *et al.*, 2019b) conducted a study to solve aforementioned problem with vehicle routing and application of simulated annealing. Another aspect of real life application comprehends the disaster relief. In that aspect, (Davoodi and Goli, 2019) proposed a study which concerns the disaster relief model based on covering tour in Iran and solution is gathered via application of hybrid benders decomposition and variable neighborhood search approach. From the same point of view, an uncertain integrated approach is adopted for simultaneously locating temporary health centers in affected areas,

assigning affected regions to these centers and delivering supplies to these centers by utilizing harmony search algorithm (Alinaghian and Goli, 2017). Another problem which has wide range of application is the p-hub median problem. Ghaffarinasab *et al.* (2020) proposed a study focuses on p-hub median problem under hose and hybrid demand uncertainties and solution is represented with Tabu Search algorithm. In addition to aforementioned studies, a product portfolio problem (Goli *et al.*, 2019), cell formation and production scheduling (Goli *et al.*, 2021), demand prediction (Goli *et al.*, 2020; 2018) and disaster relief locating and routing problems (Goli and Malmir, 2020) are focused in literature for real life applications.

In the proposed study, Quadratic Assignment Problem (QAP) is considered which deals with allocating a set of facilities to a set of locations, with the cost being a function of the distance and flow between the facilities (Erdogan and Tansel, 2011). The QAP was introduced by (Koopmans and Beckmann, 1957) as a mathematical model for the location of a set of indivisible economical activities (Lawler, 1963). Since then, the

QAP, one of the most difficult problems in the NP-hard class, models many real-life problems in several areas such as facilities location (Elshafei, 1977), parallel and distributed computing (Czapiński, 2013), combinatorial data analysis (James *et al.*, 2009) and image processing (Schellewald *et al.*, 2007). For a review of methodological and case-study based papers in QAP, the reader is referred to (Loiola *et al.*, 2007) and Bhati and Rasool (2014).

Additionally, several heuristic and meta-heuristic approaches such as particle swarm optimization algorithm (Pradeepmon *et al.*, 2018), artificial bee colony optimization algorithm (Dokeroglu *et al.*, 2019) and integrated genetic algorithm with tabu search (Zhang *et al.*, 2020) have been proposed for QAP due to its NP-hard nature.

As can be seen above, the QAP has been drawing researchers' attention worldwide, not only because of its complexity and theoretical importance, but also because of its practical ability. In practical studies, facility layout or location problems are at the first place where the QAP is used (Hosseini-Nasab *et al.*, 2018). However, the papers which apply QAP formulation to a service sector problem are very limited (Saremi *et al.*, 2008). One of the studies that is applied on service sector considers the patient rotation in hospital by utilizing QAP (Feng and Su, 2015). Patient rotation is modeled as integer programming and results demonstrate the 11.55% decrease in average walking time for Tongji Hospital. Another study that utilizes QAP problem, focuses on the virtual machine placement for cloud computing services (Stefanello *et al.*, 2019). They proposed two hybrid algorithms, which are greedy randomized adaptive search procedure and a biased random-key genetic algorithm by applying path-relinking strategy and variable neighborhood descent. Both of proposed algorithms demonstrate efficient and effective performance on small and large scale test data. The study by (Zhou *et al.*, 2019) that also considers the virtual machine concentrates on virtual machine migration for the costumers who aims to migrate their services from local clusters to cloud data centers. They generate the multi-objective integer non-linear programming which reduced to multi-object QAP and solved by optimization problem solvers. In addition, (Li *et al.*, 2019) used QAP formulation for multi-access edge computing in which energy efficient joint content placement and scheduling taken into consideration with constraints that includes wireless and backhaul transmissions. Moreover, QAP is considered to prevent the human error by locating medications in automated dispensing cabinets in the study conducted by (Pazour and Meller, 2012).

There are several QAP studies that focus on real life application and apply heuristics as a solution method. For instance, QAP is applied on website structure improvement and ant colony is utilized for solution by (Qahri Saremi *et al.*, 2008). In that aspect, genetic algorithm based approach

is applied by (Rahbari *et al.*, 2014) on wind farm layout optimization. In another study proposed by (Abdel-Basset *et al.*, 2018), whale algorithm integrated with tabu search for QAP is proposed and utilized in order to be used for locating hospital departments. In addition, (Tsutsui and Fujimoto, 2009) used parallel genetic algorithm for solving GPU computation.

In this study, the layout of a fitness center is tried to be re-designed. Our motivation to utilize layout of a fitness center derives from to demonstrate the application of existing problem from different perspective and applicability of QAP. The problem is considered as a QAP. In addition, two different heuristic approaches are applied and tested on the problem. While the sports equipment is considered as machines, their required spaces are considered as locations. Members of the fitness center are assumed as products which are visiting the sport equipment (machines) in order. Because of the 19 equipment, the problem size is 19×19 . All the required data (flow and distance) are gathered from a fitness center in Gaziantep, Turkey. The QAP is solved as an IP formulation using GUROBI package program. Although IP model provides the optimal solution, 2-opt and tabu search algorithms are applied to reach the optimal solution in a reasonable time. Although 2-opt algorithm is a heuristic approach for local search, there are several studies which apply 2-opt algorithm in QAP papers. Okano *et al.* (2018) proposed study that investigates the local search techniques on QAP problem and divided 2-opt into two strategies which are first improvement and best improvement. In addition, (Chaparala *et al.*, 2014) conducted study that applies 2-opt on QAP to compute capabilities of current GPUs in which, 2-opt demonstrates computed cost is within the 0.1% of best known value and results are gathered in reasonable time even for large datasets. In terms of tabu search applications in QAP, (Zhu *et al.*, 2010) proposes a single instruction multiple data tabu search by utilizing graphic hardware acceleration on QAP and they achieved the reach solution 20-45 time faster than standard CPU code. Dejam *et al.* (2012) generates the algorithm by combining cuckoo and tabu search and they received more optimized solution through applications than single algorithms such genetic and honey bee algorithms. Another study conducted by (Fescioglu-Unver and Kocar, 2011) applies two strategies to improve tabu search on QAP instances.

A brief review above indicates that there is a still gap in the QAP application in service systems. To the best knowledge of the authors, the observed contributions are summarized below:

- Considering a fitness center layout problem as a QAP firstly in the literature
- Bringing a real life case problem to the QAP literature
- Proposing and testing two different heuristic/meta-heuristic approaches

In this study, the applied mathematical formulation and the algorithms of 2-opt and tabu search are described through section 2. After that the real case of a fitness center is introduced in section 3. The results of three approaches and comparison with the current layout are discussed in section 4. Section 5 briefly concludes the paper and gives the future research directions regarding QAP.

Methodology

In this section, the applied approaches namely integer programming, 2-opt and tabu search algorithms are described, respectively.

Mathematical Formulation of QAP

In this study, the initial formulation by (Koopmans and Beckmann, 1957) is used. The notations of the model are given in Table 1.

Table 1: Notations

<i>Sets</i>	i, j	Facility (sports equipment)
	k, l	Locations (an area on the fitness center layout)
<i>Parameters</i>	n	Number of facilities (number of locations)
	a_{kl}	The distance between locations k and l
	b_{ij}	The flow (number of members) per unit time between facilities i and j
<i>Decision variable</i>	x_{ik}	1, facility (sports equipment) i is assigned to location (an area on the fitness center layout) k ; 0, otherwise

Table 2: The pseudo code of 2-opt algorithm

```

iteration ← 1
while iteration < max_iter do
    Create a random solution T (T represents a single dimensional sequence of sports equipment assuming that each element of the sequence is assigned to areas A to S respectively, such as the first element of T is assigned to area A, the second element of T is assigned to area B and so on.)
    Calculate Obj(T) = objective function value of T
    Tbest ← T, Objbest ← Obj(T)
    repeat
        Max_impr ← 0
        for i = 1 to n-1 do
            for j = i+1 to n do
                Calculate Impr(ij) = Improvement on the Obj(T) when ith and jth elements of the T are swapped
                if Impr(ij) > Max_impr
                    Max_impr ← Impr(ij)
                    i* ← i
                    j* ← j
                end if
            end for
        end for
    if Max_impr > 0
        T ← swap i*th and j*th elements of T
        Calculate Obj(T)
    end if
    until Max_impr = 0
    if Obj(T) < Objbest
        Objbest ← Obj(T)
        Tbest ← T
    end if
    iteration ← iteration + 1
end while
Report Objbest and Tbest

```

The Koopmans–Beckmann formulation of the QAP is as follows:

Model:

$$\min \sum_{i=1}^n \sum_{j=1}^n \sum_{k=1}^n \sum_{l=1}^n a_{ij} b_{kl} x_{ik} x_{jl} \quad (1)$$

Subject to:

$$\sum_{i=1}^n x_{ij} = 1 \quad \forall_{j=1, \dots, n} \quad (2)$$

$$\sum_{j=1}^n x_{ij} = 1 \quad \forall_{i=1, \dots, n} \quad (3)$$

$$x_{ij} \in \{0, 1\} \quad \forall_{i, j=1, \dots, n} \quad (4)$$

The objective function (Eq. 1) is to assign each sports equipment to a location on the fitness center layout such that the total flow \times distance is minimized. Constraints (2) and (3) imply that sports equipment can be assigned to only a location and vice versa. Constraint (4) is the sign constraint shows the binary decision variable. Due to nonlinearity of the objective function, many authors have proposed methods for linearizing the quadratic form of the objective function (Eq. 1) by introducing additional variables. The linearization method of (Frieze and Yadegar, 1983) is used in this study.

2-opt Algorithm

The 2-opt algorithm which is one of the most famous simple local search algorithms was first proposed by (Croes, 1958) for Travelling Salesman Problem (TSP).

The algorithm starts with an initial TSP tour and considers the swapping of the first and the second nodes of the initial solution. If the resulting solution's objective function value is better than that of the initial solution, then these node pair is stored as a candidate for future consideration; otherwise, it is discarded. Then the algorithm considers the swapping of the first and the third nodes. If this exchange generates a better solution, then it is stored as a candidate for future consideration; otherwise, it is discarded and so on. Thus, whenever a better candidate node pair is found, the algorithm discards the previous best candidate. This procedure continues until all the pair-wise exchanges are considered (Bashiri and Karimi, 2012).

In this study, the 2-opt algorithm is applied to above mentioned fitness center layout problem as follows: The solution is encoded as a single dimensional sequence of the sports equipment such as a single dimensional node visiting sequence of a TSP problem. While decoding, it is assumed that each element of the sequence is assigned to areas (locations) A to S respectively. For example the first element of the encoded solution is assigned to area A, the second element is assigned to area B and so on. Finally the objective function is calculated by summing flow \times distance.

2-opt algorithm produces a single improved solution for an initial solution. Thus, for the above mentioned fitness center layout problem, the 2-opt algorithm is repeated for a number of iterations in which the algorithm starts with different initial solutions. Pseudo code of the 2-opt algorithm for the fitness center layout problem is given in Table 2.

Tabu Search

Tabu search algorithm is introduced by (Glover, 1989), which focuses on the local search. The main part of the Tabu search algorithm is updating the best solution list during the searching and whole solutions gather a priority value. In addition, Tabu search includes a tabu list to store the history of the search process, a mechanism for acceptance or rejection of a new allocation in the neighborhood and a

mechanism that leads the change procedure between neighborhood diversification and intensification strategies (Loiola *et al.*, 2007). Pseudo code of applied Tabu search in proposed study is given in Table 3.

Table 3: The pseudo code of Tabu search algorithm

```

neighbors, number of iteration, N = number of generated neighbors
current_solution = create initial solution randomly with respect to dimension of given input data (flow and distance matrix)
number of iteration = decide on maximum number of iteration
Create a list for short term memory
Create a list for long term memory
Create threshold length value for short term memory
while number of iteration > 0:
    Best_solution = current_solution
    move on the neighbor solutions from current_solution
    cost = store the sequence of neighbor solutions
    for index to length(neighbors):
        calculate the cost for each neighbors
    sort the neighbors by cost
    rank = sorted list of the neighbors by cost
    for j to N:
        check the neighbor is already in created solution or not
        if neighbor is not in created solution:
            if length of short term memory > threshold length value:
                Take the list of short term memory from the 1st element
            if current_solution not in the long term memory:
                Penalize the current_solution with 1
                if objective value of current_solution < objective value of best_solution:
                    best_solution = current_solution
            else:
                cur_cost = objective value of current_solution penalized by 1
                increment the long term memory for the current visit
                if cur_cost < best solution:
                    best_solution = current_solution
                break
        elif objective value of neighbors[j, :-2] < objective value of best_solution:
            current_solution = neighbors[j, :-1]
            append the neighbors[j, -2:] to short term memory
            if length of short term memory > threshold length value for short term memory:
                update short term memory without 1st element
            if current_solution not in long term memory:
                penalize current_solution by 1 (set key penalty to one)
            best_solution = current_solution
        else:
            cur_cost = objective value of current_solution + penalization in long term memory for current_solution
            increment the frequency for the current visit
            if cur_cost < objective value of best_solution:
                best_solution = current_solution
    number of iteration += 1
    
```

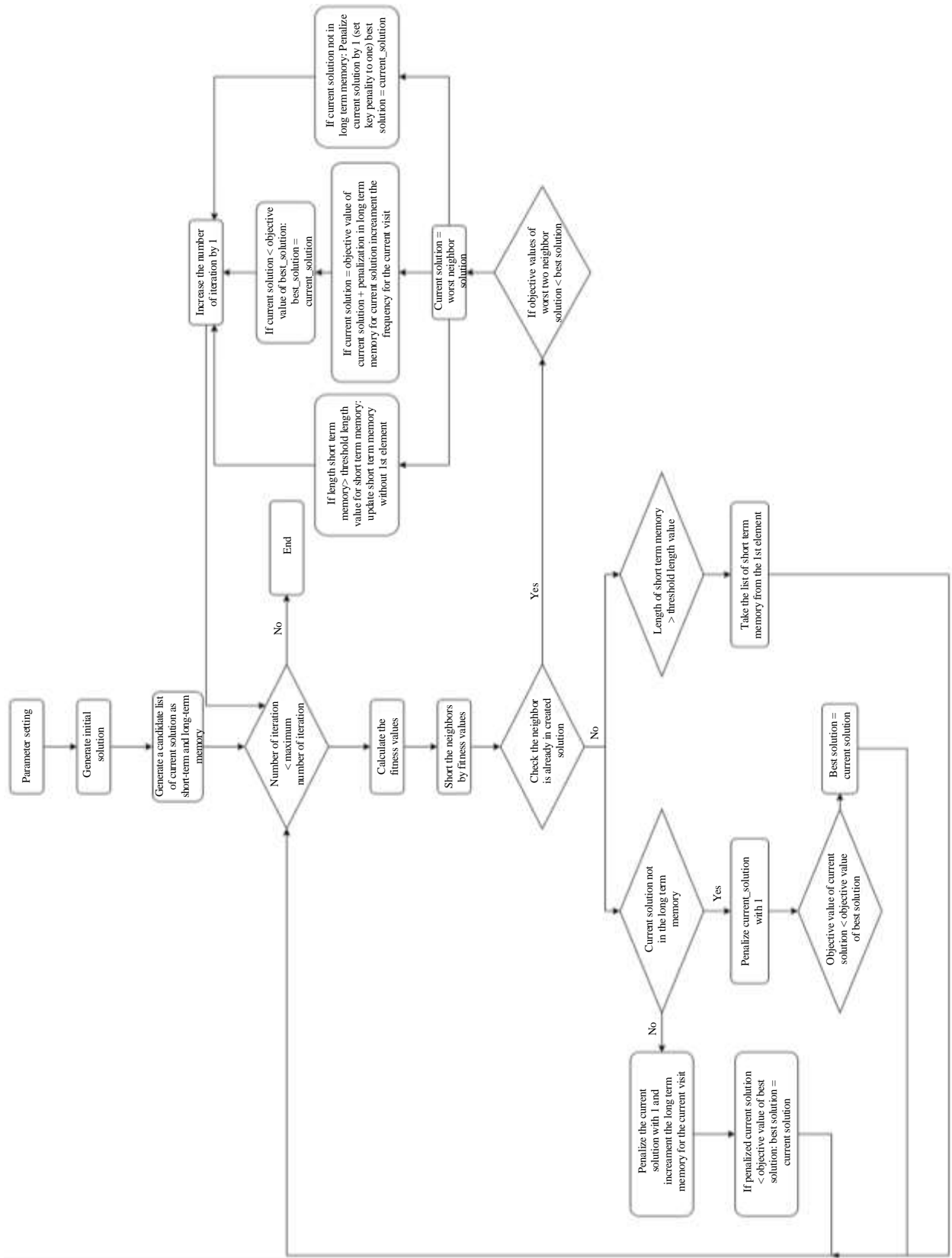


Fig. 1: Flowchart of tabu search algorithm

Detailed demonstration of tabu search is given in Fig. 1. It can be said that there is a decision box that checks the whether the solution is already generated or not. According to the answer, procedure of tabu search implemented, which are aspiration criteria and tabu list operations) till the maximum number of iteration reached.

Case Study

The layout optimization of fitness center in Gaziantep University campus is considered in this study. There are totally 19 sports equipment in the fitness center. Sports equipment is shown in Fig. 2 with their codes.

Due to the number of sports equipment, the layout of the fitness center is divided into 19 parts from A to

S as shown in Fig. 3. The current layout of the fitness center is also shown in Fig. 4. For instance, the sport equipment BEP is located on the A area.

Although there is a current layout, the manager asks a new layout which minimizes the total distance/time of people. Due to narrowness of the place, crowded and looking for next sport equipment is not desired. The problem is assigning 19 sports equipment (Fig. 2) to 19 places (Fig. 3) while minimizing the total walking distance. There are mainly two parameters for the QAP as mentioned in the previous section. $A = (a_{kl})_{n \times n}$ which corresponds the distances between areas are calculated using AutoCAD. The distance matrix is given in Table 4. It must be noted that the distance matrix is symmetric.



Fig. 2: 19 sports equipment in the fitness center



Fig. 3: Layout of the fitness center



Fig. 4: Current layout of the sports equipment

Table 4: Distances between areas (cm)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
A	0	200	800	1000	1300	1500	1800	2000	2300	2500	400	800	1000	1300	1500	1800	2000	2300	2500
B	200	0	300	800	1100	1300	1600	1800	2100	2300	400	600	800	1100	1300	1600	1800	2100	2300
C	800	300	0	200	800	1000	1300	1500	1800	2000	700	300	500	800	1000	1300	1500	1800	2000
D	1000	800	200	0	300	800	1100	1300	1600	1800	900	500	300	500	800	1100	1300	1600	1800
E	1300	1100	800	300	0	200	800	1000	1300	1500	1200	800	600	300	500	800	1000	1300	1500
F	1500	1300	1000	800	200	0	300	800	1100	1300	1400	1000	800	500	300	600	800	1100	1300
G	1800	1600	1300	1100	800	300	0	200	800	1000	1700	1300	1100	800	600	300	500	800	1000
H	2000	1800	1500	1300	1000	800	200	0	300	800	1900	1500	1300	1000	800	500	300	600	800
I	2300	2100	1800	1600	1300	1100	800	300	0	200	2200	1800	1600	1300	1100	800	500	300	500
J	2500	2300	2000	1800	1500	1300	1000	800	200	0	2400	2000	1800	1500	1300	1000	800	500	300
K	400	400	700	900	1200	1400	1700	1900	2200	2400	0	400	900	1200	1400	1700	1900	2200	2400
L	800	600	300	500	800	1000	1300	1500	1800	2000	400	0	200	800	1000	1300	1500	1800	2000
M	1000	800	500	300	600	800	1100	1300	1600	1800	900	200	0	300	800	1100	1300	1600	1800
N	1300	1100	800	500	300	500	800	1000	1300	1500	1200	800	300	0	200	800	1000	1300	1500
O	1500	1300	1000	800	500	300	600	800	1100	1300	1400	1000	800	200	0	300	800	1100	1300
P	1800	1600	1300	1100	800	600	300	500	800	1000	1700	1300	1100	800	300	0	200	800	1000
Q	2000	1800	1500	1300	1000	800	500	300	500	800	1900	1500	1300	1000	800	200	0	300	800
R	2300	2100	1800	1600	1300	1100	800	600	300	500	2200	1800	1600	1300	1100	800	300	0	200
S	2500	2300	2000	1800	1500	1300	1000	800	500	300	2400	2000	1800	1500	1300	1000	800	200	0

Table 5: From/to table of sports programs

Pr.	BOL	ELB	ECT	SHP	LPR	LCR	LEX	TRO	CCR	SHE	VRLP	VB	TRB	PRT	PRE	BEP	SRO	MAT	DSL
1	1	1			1		1		1		1	1		1					
2				1	1										1		1		
3			1		1		1		1	1						1	1		
4				1	1			1		1		1	1		1				
5		1		1	1			1						1		1	1	1	1
6					1				1	1	1	1	1		1		1		1
7						1	1	1		1	1	1	1	1		1			1
8	1	1			1		1				1	1							
9			1		1		1		1	1	1					1	1		
10						1		1		1	1			1	1	1			1

Table 6: Flows between equipment per day

	BEP	BOL	CCR	DSL	ECT	ELB	LCR	LEX	LPR	MAT	PRE	PRT	SHE	SHP	SRO	TRB	TRO	VB	VRLP
BEP	0	0	18	2	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0
BOL	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0
CCR	0	0	0	10	0	0	0	15	0	0	0	0	0	0	0	0	0	0	23
DSL	23	0	0	0	0	0	0	0	10	0	27	62	0	15	25	0	0	0	5
ECT	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0
ELB	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	25	0
LCR	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LEX	0	20	0	0	18	5	5	0	0	0	0	0	0	0	0	0	0	0	0
LPR	0	0	0	43	0	0	0	0	0	0	0	0	0	25	15	0	0	10	0
MAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PRE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	10
PRT	0	0	20	10	0	0	0	20	0	0	0	0	0	0	0	0	15	0	7
SHE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SHP	0	0	0	30	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0
SRO	10	0	10	30	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
TRB	0	0	0	0	0	0	2	5	83	0	0	0	0	10	0	0	0	0	0
TRO	0	0	0	0	0	10	0	0	0	0	0	0	22	0	0	0	0	15	0
VB	0	5	0	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0
VRLP	2	0	0	35	0	0	0	5	0	0	0	0	0	3	0	0	0	0	0

The second matrix for the QAP is related with the relation between sports equipment (stations). To do so, sports programs which are followed by the members are investigated. There are totally 10 different programs which visit different sports equipment in different orders. 10 sports programs are given in Table 5 (from/to table) with their corresponding sports equipment. According to Table 5, while a member who follows the first program has to visit BOL-ELB-LPR-LEX-CCR-VRLP-VB and PRT sport

stations, a member who follows the second program has to visit SHP-LPR-PRT and SRO stations. All programs are followed by different numbers of members. Therefore, the activity relations between equipment are calculated by multiplying the numbers in Table 5 and the number of members of each sport program. The final $B = (b_{ij})_{n \times n}$ matrix which correspond the flows between equipment is given in Table 6. For instance, 18 members are visiting CCR equipment after BEP equipment in one day.

Apart given the parameters above, the assumptions of the study are mentioned below:

- The required area of each sports station is equal and same
- Every member follows the sports program in given order on each day
- Waiting for the equipment is ignored

Results and Discussion

The case given in previous section is solved using three different solution techniques in this section. All runs are taken on a server with 3.00 GHz Intel Core processor and 2 GB of RAM. The IP formulation is applied using GUROBI 9.1 package program. The optimal solution is obtained as 427,800.00. The computation time required to solve the model is 4,400.00 sec. The optimal assignment is shown in Table 7 and Fig. 5.

When the optimal layout is compared with the current layout, it is clear to see that all locations of sports equipment are changed. Total traveled distance \times flow

equals to 960,700.00 in the current layout. Optimal solution reduces the total distance \times flow value to 427,800.00 by 55.47%. Although the IP finds the optimal solution, the computational time which is greater than one hour does not satisfy the decision maker. Therefore, 2-opt and tabu search algorithms are tested on the same case. 2-opt is coded using C#. The iteration is limited as 500. The algorithm is run ten times and optimal solution is obtained in all runs. The optimal solution is found in 2.5 sec less than 500 iterations. Tabu search algorithm is also applied to make a comparison between 2-opt algorithm. Tabu search algorithm is coded by utilizing Python. The iteration is limited as 8000. The algorithm is run ten times as 2-opt algorithm. However, optimum solution is gathered only seven of the ten runs which is shown in Table 8. According to Table 8, the computation time varies between 8.50 and 67.00 sec. Figure 6 demonstrates the number of iterations and corresponding objective values. From the Fig. 6, it can be said that tabu search algorithm fluctuates till 7000 iterations. However, it becomes roughly stable after 7000 iterations.

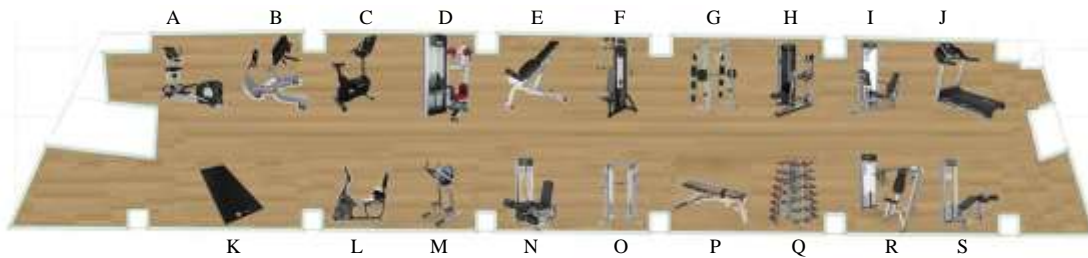


Fig. 5: Optimal layout of the sports equipment

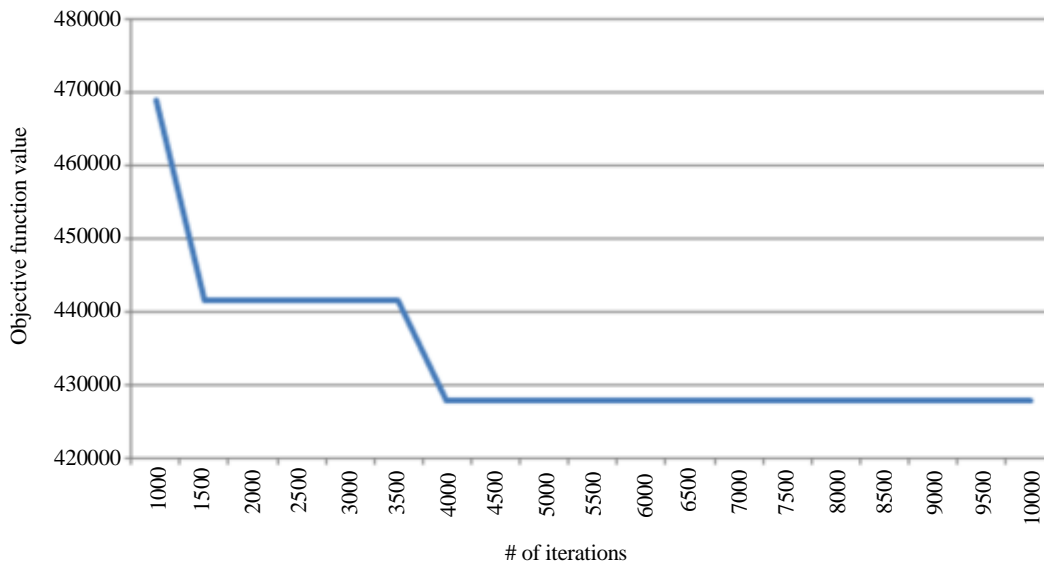


Fig. 6: Convergence graph of tabu search algorithm

Table 7: Optimal assignments

Location	A	B	C	D	E	F	G	H	I	J
Equipment	ECT	SHE	VB	TRO	PRE	VRLP	BEP	SRO	LPR	TRB
Location	K	L	M	N	O	P	Q	R	S	
Equipment	MAT	ELB	BOL	LEX	CCR	PRT	DSL	SHP	LCR	

Table 8: Summary of tabu search runs

Runs	1	2	3	4	5
Found Solution	469,000.00	427,800.00	427,800.00	427,800.00	427,800.00
Elapse Time (sec)	23.60	8.50	19.40	19.20	17.80
Runs	6	7	8	9	10
Found Solution	427,800.00	466,000.00	469,000.00	427,800.00	427,800.00
Elapse Time (sec)	13.40	65.00	67.00	51.60	24.40

Conclusion

In this study, the allocation of sports equipment to the locations in a fitness center is studied. The considered problem contains 19 sport stations (equipment) for 19 alternative locations. Two required information namely the distance matrix between locations and the flow matrix (the number of members who visit the equipment in order) between sports equipment are obtained. The problem is modeled as a QAP and an integer programming formulation is applied. Although the optimal solution of the problem is obtained by the integer programming model using GUROBI package, two heuristic approaches namely 2-opt and tabu search algorithms are also applied to find the feasible/optimal solutions in a reasonable time. Optimal solution is also achieved using 2-opt and tabu search algorithms in very short computational times (less than 10 seconds) compared to the integer programming model (4.400 sec). The optimal solution shows that the new layout is 55.47% better than the current layout in terms of the total traveled distance \times flow. From the managerial perspective, it provided that maximum profit of fitness center is accomplished by accurate layout out design and customer satisfaction is managed by reducing waiting time for each station. Therefore, more accurate managerial decisions can be made by gathering efficient and effective layout.

For the future studies, (i) the required spaces of each sports equipment should be considered as unequal, (ii) a decision support system should be also developed to provide flexibility for decision makers, (iii) an exact solution approach should be developed for large sized problems and (iv) the model should be applied to large GYM centers that include more equipment.

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Author's Contributions

İbrahim Miraç Eligüzel and Yakup Atasagun: Participated in drafting the research problem, outlining the solution procedure, and checking the methodology and results.

Eren Özceylan: Helped in writing the article.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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