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Stochastic Facility Layout Planning Problem: A Meta-heuristic and Case Study

Nima Moradi*

Department of Industrial Engineering, Sharif University of Technology, Tehran, Iran

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Abstract

Facility layout is one of the most important Operations Management problems due to its direct impact on the financial performance of both private and public firms. Facility layout problem (FLP) with stochastic parameters, unequal area facilities, and grid system modeling is named GSUA-STFLP. This problem has not been worked in the literature so that to solve GSUA-STFLP is our main contribution. In this paper, we have first presented an integer nonlinear programming model which aims to minimize the cost of material handling. Then, a metaheuristic SA-based algorithm is proposed. Our proposed SA is able to generate feasible solutions by a local search operator to explore and exploit the solution space. Next, problems with different sizes besides the real case study have been solved. The computational results show the capability of the proposed SA to obtain the solutions with high quality in a short time.

Keywords:
Stochastic Facility Layout Problem
Un-equal Area
Grid System
Simulated Annealing

* **Correspondence E_mail**: nima_moradi99@yahoo.com

INTRODUCTION

Nowadays, managers and factory owners are trying to reduce the costs and manufacturing expenses in order to survive and thrive in the competitive environment of the different industries. This cannot be reached unless managers decide to design and plan an appropriate layout of the facilities inside the factory. In addition, we know that the improved facility layout has a direct impact on the financial performance of both private and public firms (Farahani & Hekmatfar, 2009). Deciding to locate the facilities appropriately is known as facility layout planning problem (FLP) in the literature of operations management (OM). So FLP determines the right location of the existing facilities by considering the various and even controversial criteria such as material handling cost, safety factors, closeness rate and etc.

LITERATURE REVIEW

In the literature, the type of the FLP parameters has been considered by three approaches namely deterministic, stochastic and fuzzy numbers. In the first approach (deterministic), the demand for products is considered deterministic which leads to constant material flow between facilities (Rosenblatt & Kropp, 1992). In the stochastic approach, unlike the deterministic one, FLP parameters have the known earned value and variance with a specific probability distribution function which results in stochastic from-to flow matrix or trip frequency between facilities. The fuzzy approach can be divided into two types, fuzzy numbers and linguistic patterns (Enea et al., 2005). FLP with the stochastic approach is named STFLP, which is able to model the real environment with better details although the computational complexity increases due to the larger solution space.

As it was mentioned, in STFLP, each array in from-to material flow matrix is random with a specific probability distribution function. In addition to the stochastic flow matrix, the facility layout is just designed in one period. On the other hand, if we design the facility layout for multiple periods with constant flow matrix, that facility layout will be dynamic facility layout planning (DFLP) (Zhu et al., 2018), (Turanoğlu & Akkaya, 2018), which indicated the difference between STFLP and DFLP (Hosseini-Nasab & Emami, 2013). In DFLP, if the number of periods is considered single, that will be static FLP (SFLP). Furthermore, there are two main classes for STFLP, equal-area STFLP (EA-STFLP) and unequal-area STFLP (UA-STFLP). In EA-STFLP, every facility has the same area which is unreal assumption according to the real-world situations (Derakhshan et al., 2016). On the other hand, UA-STFLP deals with the different areas for each facility which leads to increasing the applicability of the model to be implemented in the real case studies.

Additionally, UA-STFLP is divided into two types (based on modeling the site floor) which are continuous and grid-system approaches. By continuous modeling, each facility can be located everywhere in the site floor while satisfying the non-overlapping constraint (fig.1). In grid-system, the site or plant floor is divided into multiple square units, which are similar to each other and mutually exclusive and together construct the whole site floor (fig. 2). Besides the site floor modeling, the stochastic parameters of STFLP can be presented by i) material flow matrix with stochastic numbers which their probability distribution is a priori or ii) different material flow matrixes with a specific probability for each matrix in which every matrix can be considered as one scenario. Based on (Mazinani et al., 2013), various problems of FLP are NP-hard which indicates the ineffectiveness of the exact methods for these kinds of problems. Therefore, it is better to choose the heuristics or metaheuristics methods instead of exact approaches especially when the FLP is stochastic, un-equal and grid-system.

Fig. 1. Continuous representation (modeling) of the facility layout problem

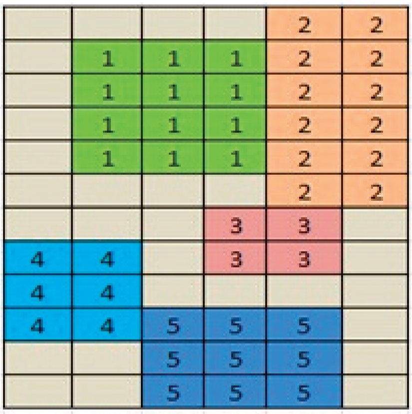

Fig. 2. Grid system representation (modeling) of the facility layout problem

Moreover, in the literature, unequal-area facility layout or UA-FLP has been studied a lot. In (Kang & Chae, 2017), a harmony search (HS) heuristic algorithm is proposed to solve the FLP with un-equal facilities which are rectangular and the site space is modeled continuously by slicing tree structure. The results show that the proposed algorithm is as efficient as the previous solution techniques. In (Allahyari & Azab, 2018), a mixed-integer nonlinear programming model for UA-FLP is developed which is solved by a multi-start search simulated annealing (SA). Also, facilities are rectangular and have no permission to rotate. The site floor also is modeled by continues approach like the previous paper. We can see similar studies which are investigated UA-FLP with continues modeling in the literature, for example (García-Hernández et al., 2013) which has solved the problem by an interactive genetic algorithm (IGA), (Ripon et al., 2013) has proposed the variable neighborhood search (VNS) with an adaptive scheme to solve the UA-FLP in a continuous site floor and we can see the other meta-heuristics for UA-FLP such as artificial immune system (AIS) (Ulutas & Kulturel-Konak, 2012), hybrid genetic algorithm (Hasda, 2017) and Non-dominated Ranking Genetic Algorithm (NRGA) (Aiello et al., 2013), Particle Swarm Optimization (PSO) (Liu et al., 2018), Coral reefs optimization algorithm (García-Hernández et al., 2019).

Based on the reports of (Singh & Sharma, 2006), most of the FLP problems are modeled mathematically as a quadratic assignment problem (QAP) in which the facilities with the number of n have to be allocated to n locations. Although QAP is a very applicable and simple model, its assumptions such as considering each facility as a single point without dimension make it impractical most of the time. In other words, QAP is not able to model the continuous site floor when each facility has its own dimensions. Instead of QAP, some mathematical models have been proposed for FLP (Montreuil et al., 1993), (Kim & Kim, 2000), (Chan et al., 2003), (Allahyari & Azab, 2018) and etc. As mentioned above, UA-FLP assumes that parameters are deterministic. In fact, UA-STFLP will be more realistic than UA-FLP due to its stochastic nature of the product demand and material flow between facilities.

In (Rosenblatt & Kropp, 1992), STFLP is studied by considering the equal area for each facility. It has modeled the problem as QAP with different scenarios. Each scenario has a specific from-to flow matrix with mutually exclusive probabilities. Finally, they have shown the robustness of the proposed solution procedure for EA-STFLP by a simulation model. One of the first works which have studied UA-STFLP is (Kulturel-Konak et al., 2004). They have considered UA-STFLP with both production uncertainty and routing flexibility. Also, they proposed a Tabu Search (TS) algorithm and the flexible bay structure to solve the UA-STFLP. Also, (Norman et al., 2006) has also studied UA-STFLP with the continuous approach and flexible bay structure like the previous article but a GA as an optimization method. Additionally, (Derakhshan Asl et al., 2016) has studied UA-STFLP by assuming the fixed shape for each facility during the iteration of the algorithm. A mixed-integer non-linear programming formulation is suggested for UA STFLP with stochastic product demands. Their model is based on the continuous site floor which has been solved by an improved covariance matrix adaptation evolution strategy (CMA ES). As a final point, (Meller & Gau, 1996), (Singh & Sharma, 2006) and (Hosseini-Nasabet al., 2018) are recommended to review concepts and definitions of FLP problems.

By reviewing the literature of FLP, we can see that UA-STFLP with grid-system (GSUA-STFLP) has not been studied in according to our best knowledge. In GSUA-STFLP, there are stochastic parameters and un-equal area facilities that the site floor is modeled with a grid-system approach. Actually, in this paper, we have first proposed an integer nonlinear mathematical model in which the objective function is to minimize the material handling cost and the constraint of non-overlapping between facilities has to be satisfied. Due to the NP-hardness of the problem, a metaheuristics algorithm based on SA is proposed. Finally, in order to show the efficiency of the proposed solution method, SA has been implemented in small and large problems, and also a real case study. As a result, the methodology of this paper is shown in fig. 3.

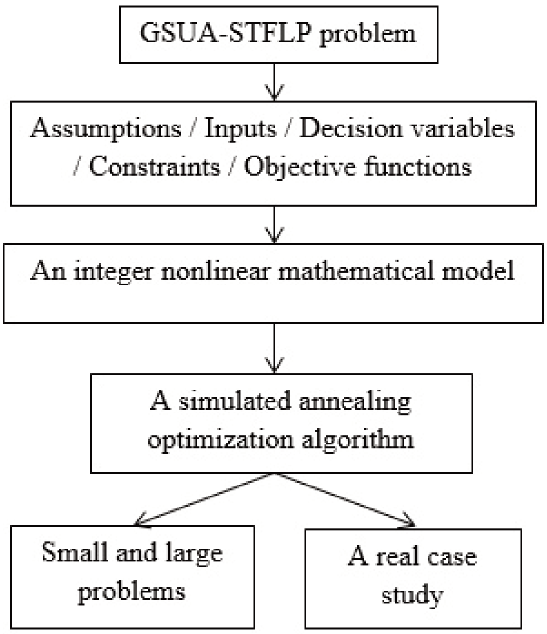

Fig. 3. The methodology of this paper (steps of the solving GSUA-STFLP)

In the following, in the next section, assumptions of the problem and an integer nonlinear mathematical programming for GSUA-STFLP are presented. Then, in the fourth section, the optimization algorithm based on SA is proposed. In the fifth section, computational results of the different problems and real case study are shown. Finally, the concluding remarks and suggestions for future studies are presented in the sixth section.

A MATHEMATICAL MODEL FOR GSUA-STFLP

In this section, a mathematical model has been presented for GSUA-STFLP. In fact, GSUA-STFLP is FLP in which facilities have different areas and site floor is neither discrete nor continuous but grid system. First of all, the presumptions of the problem are presented below:

- Facilities are two-dimensional and rectangle with different dimensions.
- The area of every unit of the grid system is 1×1 square meter.
- The rotation of each facility is not permitted.
- The distance between two facilities is calculated by Euclidean distance which is obtained by Euclidean distance between centers of gravity of two facilities.
- From-to flow/workflow/material flow between two facilities is stochastic with definite probability distribution function.
- Facilities must not overlap with each other.
- Facilities must be inscribed on the site floor.
- The planning horizon is static (there is only one period).
- The material handling system is open-field layout. This means that the facilities do not have to be arranged in a row or multi-row or a closed ring network; however, they can be located everywhere freely.
- The objective function is to minimize the total cost of material handling between facilities which is equal to multiplication of material flow and distance between each pair of facilities (single-criterion objective function).
- The site floor, where the facilities are located at, is represented by grid system units.
- There is only one floor where the facilities are located.

To model the GSUA-STFLP mathematically, we have to define indices, parameters, decision variables, constraints and objective function of the problem.

Indexing set

- i, j indices for facilities $(i, j = 1,2,\ldots,n)$; $i \neq j$

Parameters

- f_{ij} the material flow between facility i and facility j, which is stochastic
- o_{ij} the maximum material flow between fa-

cility i and facility *j*

- t_{ij} the minimum material flow between facility i and facility *j*
- d_{ij} the Euclidean distance between facility i and facility *j*
- n the number of facilities
- A_{ij} the common area between facility *i* and facility *j*
- (X_U, Y_U) the upper limit of length and width of the site floor
- (X_L, Y_L) the lower limit of length and width of the site floor
- (l_i, b_i) the length and width of the facility *i*

Decision variable

- (u_i, v_i) the reference point of the facility *i*, which is shown in fig. 4 as red square

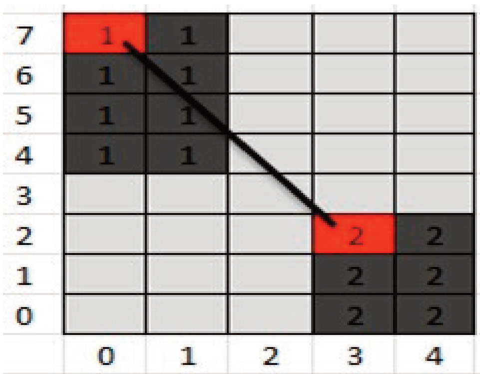

Fig. 4. GSUA-STFLP with rectangular facilities and how to calculate the distances (vertical and horizontal numbers indicate the reference point of each facility-red square)

Mathematical model

$$Min \sum_{i=1}^{n} \sum_{j=i+1}^{n} f_{ij} d_{ij} \quad (1)$$

s.t

$$\sum_{i=1}^{n} \sum_{j=1}^{n} A_{ij} = 0 \qquad i \neq j \quad (2)$$

$$u_i + l_i \leq X_U \quad (3)$$

$$u_i \geq X_L \quad (4)$$

$$v_i \leq Y_U - 1 \quad (5)$$

$$v_i - b_i \geq Y_L - 1 \quad (6)$$

$$A_{ij} = max[0, 1 + min(u_i + l_i - 1, u_j + l_j - 1) - max(u_i, u_j)] * max[0, 1 + min(v_i, v_j) - max(v_i - b_i + 1, v_j - b_j + 1)] \quad (7)$$

$$d_{ij} = \sqrt{\left(\left(u_i + \frac{l_i}{2}\right) - \left(u_j + \frac{l_j}{2}\right)\right)^2 + \left(\left(v_i - \frac{b_i}{2} + 1\right) - \left(v_j - \frac{b_j}{2} + 1\right)\right)^2} \quad (8)$$

u_i, v_i integer, $f_{ij} \sim U(t_{ij}, o_{ij})$; U is the uniform distribution function (9)

The objective function (1) minimizes the total cost of material handling between facilities. Eq. 2 controls the non-overlapping of the facilities. Eq. 3-6 determine the range of the reference point, and also they specify that the facilities must be inscribed in the site floor. Eq. 7 and (8) indicate how to calculate the common area and Euclidean distance between two facilities respectively. Finally, by (9), we know that the decision variable is an integer, and material flows between facilities are stochastic quantities which have the specific probability distribution function. As it was mentioned before, GSUA-STFLP is NP-hard. In the following, we have proposed a meta-heuristic algorithm based on simulated annealing to solve the problem in an acceptable time.

SA-BASED OPTIMIZATION ALGORITHM FOR GSUA-STFLP

According to the literature, it has proven that SA is an efficient solution technique to solve combinatorial optimization problems such as FLP (Nahar et al., 1986). SA is a stochastic and single-solution based metaheuristic which simulates the cooling process of the heated matter (Van Laarhoven & Aarts, 1987). SA starts with an initial solution which can be determined either randomly or greedy. Then, the neighbor solution is generated. The new solution is compared with the previous one. If the new solution is better, it is selected; otherwise, the new solution is accepted by a specific probability. This probability gives an ability to SA not to be trapped in a local point which leads to finding the near-optimal or even global solution (Aarts et al., 2005). The cooling process of SA is indicated by decreasing the temperature. At every temperature, generation and selection phases are done with the specific number of iterations. In other words, at each iteration 1) new solution is generated 2) better solution is selected 3) the best solution is saved in the memory. Then, by cooling the temperature, the chance of accepting worse solution is decreased and algorithm focuses on exploitation rather than exploration. SA parameters with their general definition are given in Table 1.

Table 1: SA parameters and their definitions

Parameter	**Notation**
Initial temperature	T_{max}
Final temperature	T_{min}
Cooling rate	α
The maximum iteration at each temperature	$max_{iteraion}$

To represent the decision variables of GSUA-STFLP, which are reference points of the facilities, we use a two-dimensional matrix with 2 rows and n (the number of facilities) columns as it is shown in Table 2. The proposed SA algorithm for GSUA-STFLP is presented in Alg.1. The solution generation phase and local search operator are presented in Alg. 2 and fig. 6 respectively. The movement to the neighbor solution or local search policy is designed by changing the location of one random facility at each iteration. If the new solution is feasible, the algorithm goes to the next step; otherwise, another neighbor solution is required to be generated. To summarize, by Alg. 2, SA is able to generate the various solutions and controls their feasibility and explores the total search space. Also, by local search operator, SA exploits the local solution space while trying not to be trapped in local optima with the probability in Alg. 1, line 16.

Table 2: Solution representation of GSUA-STFLP in the proposed algorithm

	Facilities			
	1	2	…	n
The abscissa of the reference point	u_1	u_2	…	u_n
The ordinate of the reference point	v_1	v_2	…	v_n

Alg. 1. The proposed SA for GSUA-STFLP

1. **Input:** Cooling schedule
2. $s=s_0$; //Initial solution with **Alg. 2**//
3. Set T_{max} ; // Initial temperature//
4. Set T_{min} ; // Final temperature//
5. Set $max\ \_iteraion$; //Maximum iteration at each temperature//
6. Set α; // α is cooling rate//
7. $T = T_{max}$; // Initial temperature//
8. **While** $(T \geq T_{min})$
9. {
10. $n = 1$;
11. **While** $(n \leq max\ \_iteraion)$ //At a fixed temperature//
12. {
13. Generation of neighbor solution *(s')* or Local Search with local search operator (fig. 5) and **Alg. 2**;
14. $\Delta E = f(s') - f(s)$;
15. **If** $\Delta E \leq 0$ **Then** $s = s'$ //Accept the better solution _ move to neighborhood//
16. **Else** Accept s' with a probability $e^{-\Delta E/T}$;
17. $n = n + 1$;
18. }
19. $\alpha \times T \rightarrow T$; //Temperature update//
20. }

Output: Display best solution;

Alg. 2. The solution generation algorithm

1. **Inputs:**
2. (X_U, Y_U); // The upper limit of length and width of the site floor//
3. (X_L, Y_L); // The lower limit of length and width of the site floor//
4. (l_i, b_i); // The length and width of the facility i//
5. $rand\ (a, b)$; // A function generating a random integer number between a and b//
6. $S[n, n]$; // An $n * n$ matrix which represents the total grid units of the site floor//
7. $F[l_i, b_i]$; // A matrix which represents the grid units of the facility i//
8. A_s; // Area of the site floor//
9. A_i; // Area of the facility i//
10. $r = 0$; // Index of infeasible solution//
11. **While** $(r < 1)$
12. {
13. **For** $(i = 1\ to\ i = n)$
14. {
15. $u_i = rand(X_L, X_U - l_i)$; // This function makes the facility i to locate inside the site floor//
16. $v_i = rand(Y_L - 1 + b_i, Y_U - 1)$; // This function makes the facility i to locate inside the site floor//
17. }
18. **For** $(i = 1\ to\ i = n)$
19. **For** $(j = 1\ to\ j = n)$
20. {
21. $S[n, n] = 0$; //There is no facility at the site floor//
22. }
23. // Facilities are located everywhere at the site floor//
24. **For** $(i = 1\ to\ i = n)$
25. {
26. **For** $(j = 1\ to\ j = l_i)$
27. {
28. **For** $(z = 1\ to\ z = b_i)$
29. {
30. $S[u_i + j, v_i + z] = i$; // Facilities are located with their numbers at the site floor//
31. }
32. }
33. }
34. $g = 0$; // g is the number of 0 in matrix $S[n, n]$//
35. **For** $(i = 1\ to\ i = n)$
36. **For** $(j = 1\ to\ j = n)$
37. {
38. **If** $(S[n, n] = 0)$ **Then** $g{++}$; //This operator calculates the number 0 in matrix S //
39. **Else** Continue;
40. }
41. **If** $(g = A_s - \sum_{i=1}^{n} A_i)$ **Then** $r{++}$; // This condition shows the non-overlapping between facilities, so the solution is <u>feasible</u>//
42. **Else** Continue; // This condition shows the overlapping between facilities, so the solution is <u>infeasible</u> and the algorithm has to go to line 12 again//
43. }

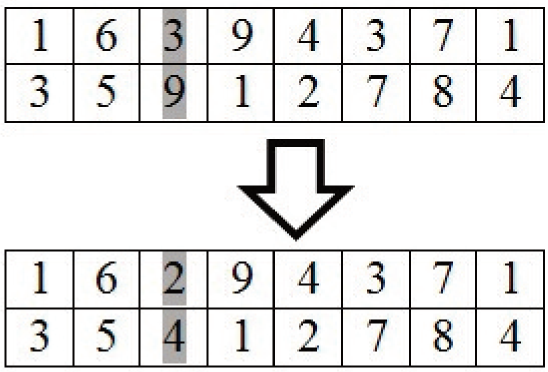

Fig. 5. Local search operator in the proposed SA--actually, this operator changes the location of one of the facilities randomly at each iteration

COMPUTATIONAL RESULTS

In this section, we have first solved various problems with different sizes to obtain the best parameters for SA and to show the capability of the proposed algorithm in large-sized problems. Also, our proposed algorithm has been encoded in C++ programming language using a 2.30 GHz Intel® Core i3 processor and 2GB memory. At first, by conducting the various experiments, the optimal values of SA parameters are obtained as Table 3. To show the capability of the proposed SA, 18 problems with sizes 3 to 60 has been solved where the computational time of each problem is less than 3 seconds. Results of the solution of the small and large-sized problems are shown in Table 4. In Table 4, inputs of GSUA-STFLP are given in which the areas of the site floor and the facilities and the material flow between facilities have the uniform distribution (for example U(1,4) means the uniform distribution between 1 and 4), and also values of SA parameters are equal to Table 3. Moreover, the convergence histories of the proposed SA for large problems are shown in fig. 6 to fig. 10, which show the improvement of the solution at each iteration.

Table 3: Optimal values of SA parameters

SA parameters	T_{max}	T_{min}	α	$max_{iteraion}$
Optimal values	100	0.01	0.98	20

Table 4: The results of the solution of small and large-sized problems with their best objective functions and computational times

Pro.	**Size***	**Length of each facility**	**Width of each facility**	**Area of site floor**	**Material flow**	**Best objective function**	**Computational time (in seconds)**
1	3	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	28	0/022
2	4	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	43	0/022
3	5	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	103	0/034
4	6	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	122	0/049
5	7	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	264	0/058
6	8	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	426	0/066
7	9	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	509	0/074
8	10	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	866	0/096
9	12	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	981	0/144
10	15	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	1875	0/188
11	18	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	3729	0/288
12	20	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	4763	0/323
13	22	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	6494	0/401
14	25	U(1,4)	U(1,4)	(2*n,2*n)	U(0,9)	9099	0/499
15	30	U(1,4)	U(1,4)	(50,50)	U(0,9)	13646	0/643
16	40	U(1,4)	U(1,4)	(50,50)	U(0,9)	28517	0/976
17	50	U(1,4)	U(1,4)	(50,50)	U(0,9)	46323	1/807
18	60	U(1,4)	U(1,4)	(50,50)	U(0,9)	76919	2/188

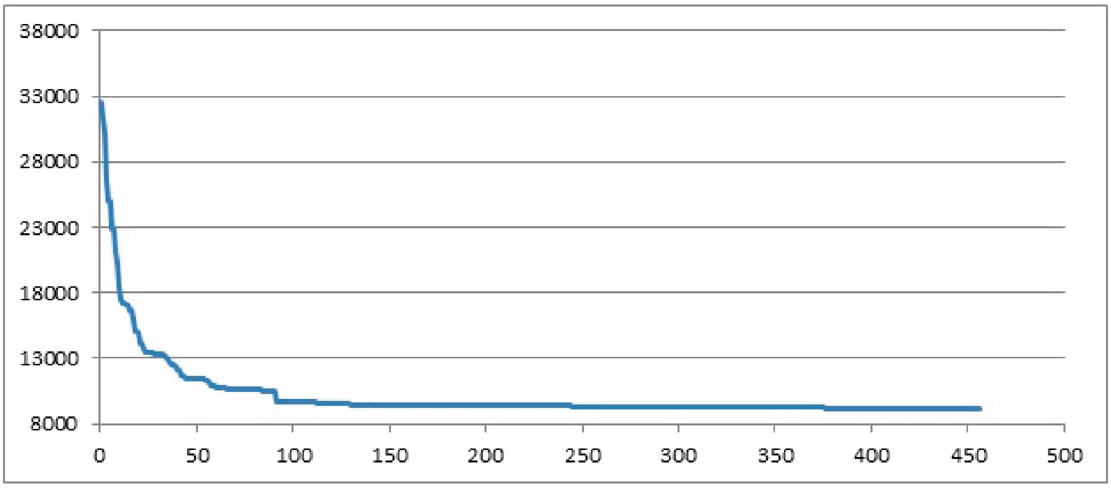

Fig. 6. The convergence history for the problem with size n=25 (vertical axis: the objective function, horizontal axis: iterations)

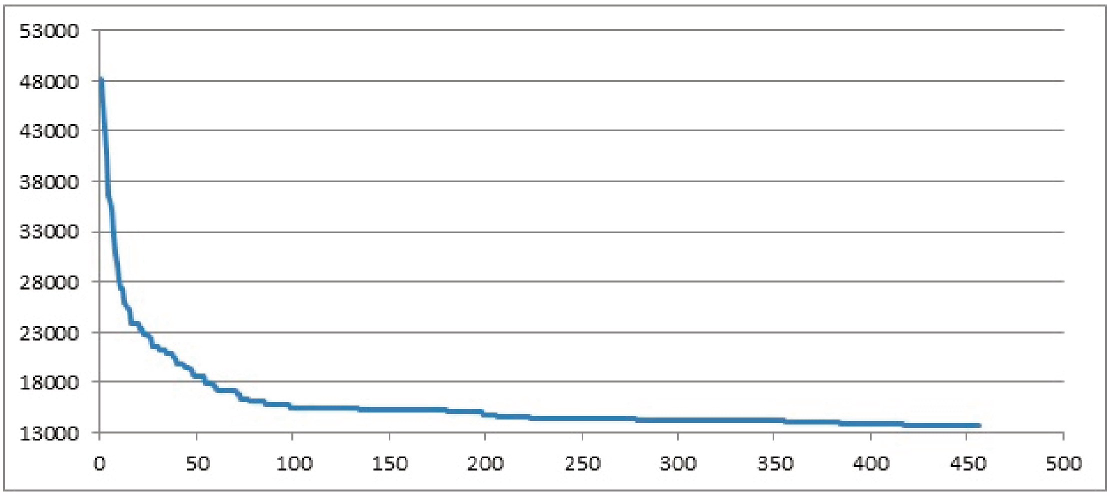

Fig. 7. The convergence history for the problem with size n=30 (vertical axis: the objective function, horizontal axis: iterations)

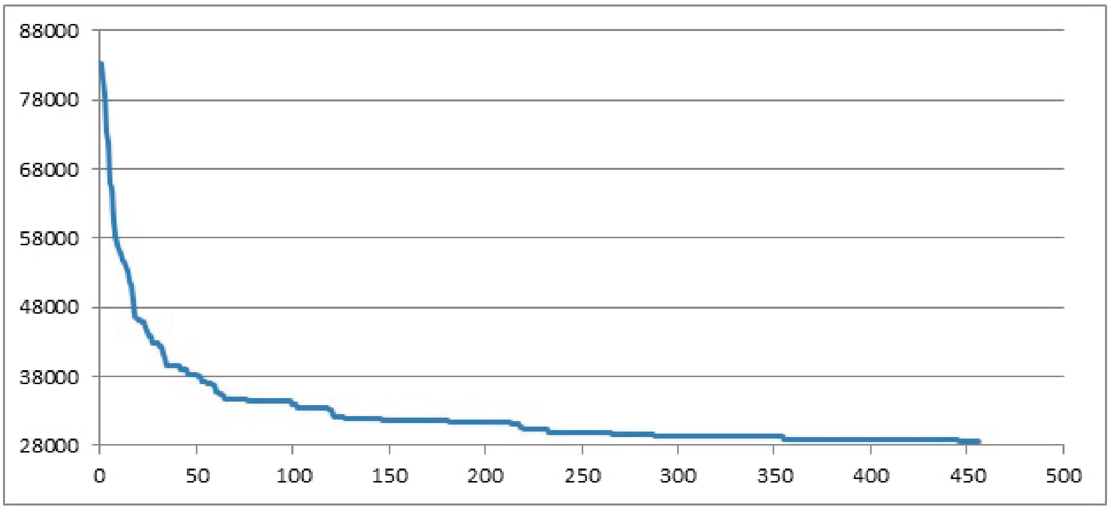

Fig. 8. The convergence history for the problem with size n=40 (vertical axis: the objective function, horizontal axis: iterations)

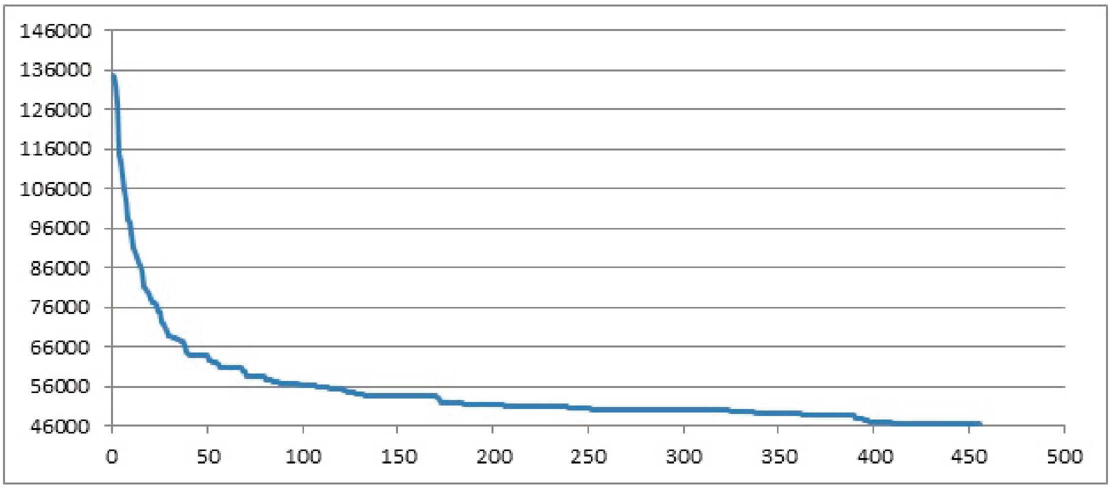

Fig. 9. The convergence history for the problem with size n=50 (vertical axis: the objective function, horizontal axis: iterations)

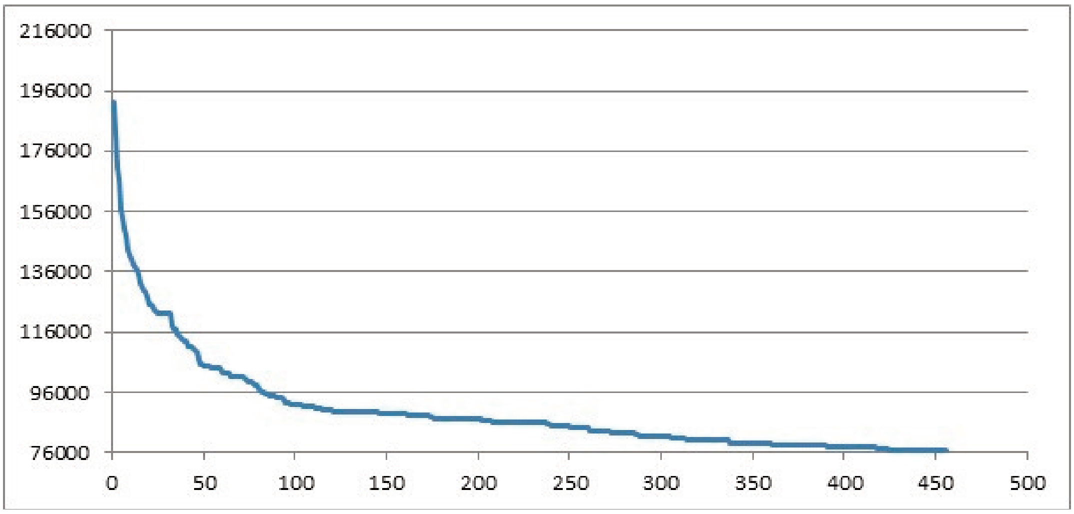

Fig. 10. The convergence history for the problem with size n=60 (vertical axis: the objective function, horizontal axis: iterations)

Solving the various problems with different sizes from small to large shows us the capability of the proposed SA to obtain the solution with high quality in an acceptable time. Now, at the end of this section, a real case study has been considered to be solved by the proposed SA. Inputs of the real case study are given in Table 4 in which area of the site floor and each facility is deterministic, but the material flows between facilities are stochastic with definite probability distribution function (uniform distribution). The optimal layout and the convergence history of the case study are shown in fig. 11 and fig. 12 respectively.

Therefore, our proposed algorithm based on SA

Table 5: Inputs of the real case study problem

	Facilities										Site floor
	1	2	3	4	5	6	7	8	9	10	
Length	30	35	30	15	20	20	10	15	5	5	50
Width	15	20	20	25	10	30	10	10	5	20	100
The material flow between the facilities	U(4,7)				All units are in meters						

0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	1	1	1	1	1	1	0	0
0	0	1	1	1	1	1	1	0	0
0	0	1	1	1	1	1	1	0	0
5	5	5	5	5	6	6	6	6	0
5	5	5	5	5	6	6	6	6	0
0	0	4	4	4	6	6	6	6	0
0	0	4	4	4	6	6	6	6	0
0	0	4	4	4	6	6	6	6	0
0	0	4	4	4	6	6	6	6	0
0	0	4	4	4	0	9	7	7	0
3	3	3	3	3	3	10	7	7	0
3	3	3	3	3	3	10	8	8	8
3	3	3	3	3	3	10	8	8	8
3	3	3	3	3	3	10	0	0	0
0	0	2	2	2	2	2	2	2	0
0	0	2	2	2	2	2	2	2	0
0	0	2	2	2	2	2	2	2	0
0	0	2	2	2	2	2	2	2	0

Fig. 11. Optimal layout of the real case study problem (each unit of grid system is equal to 5*5 meter square in the real world)

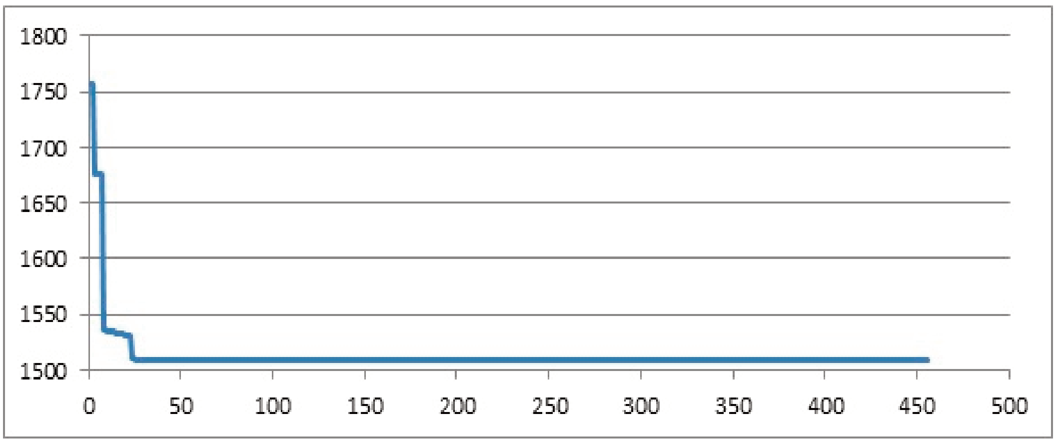

Fig. 12. The convergence history for the case study problem (vertical axis: the objective function, horizontal axis: iterations)

was able to solve the different problems and also a real case study in which dimensions of the facilities and site floor was based on the real measures. Also, the convergence histories prove the artificial intelligence of the proposed algorithm and its acceptable speed of convergence. The computational time of each problem is under the 5 seconds which shows the capability of the proposed SA to obtain the solutions with high quality in a short time.

CONCLUSIONS

In this paper, we have proposed a mathematical model for GSUA-STFLP, which has not been worked in the literature previously. Our proposed mathematical model is integer nonlinear programming, and also an NP-hard problem. To obtain the solutions with high quality in acceptable computational time, we have presented a metaheuristic algorithm based on SA. To overcome the constraints of the problem, SA with solution generation algorithm and a local search operator is proposed. Next, to show the capability of the proposed SA, we have solved the different problems with small sizes to large sizes which were size 3 to 60. All of the problems were solved less than 3 seconds which shows the high speed of the algorithm. Finally, a real case study whose inputs were from the real world cases has been selected to be solved optimally by the proposed SA. As a result, our proposed SA–based algorithm is able to solve the different problems of GSUA-STFLP. Also, the convergence histories prove the artificial intelligence of the proposed algorithm and the computational times show the capability of the proposed SA to obtain the solutions with high quality in a short time.

To future studies, the dynamic form of GSUA-STFLP is suggested which has a higher computational complexity in comparison with the other FLP variants. Also, some developments of the proposed SA can be done by defining and employing the other local search operators such as greedy approach. Solving the GSUA-STFLP by the various metaheuristics and comparisons study is another suggestion which can indicate the superiority of each algorithm.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

REFERENCES

Aarts, E., Korst, J., & Michiels, W. (2005). Simulated annealing. In *Search methodologies* (pp. 187-210): Springer.

Aiello, G., La Scalia, G., & Enea, M. J. E. S. w. A. (2013). A non dominated ranking Multi Objective Genetic Algorithm and electre method for unequal area facility layout problems. *40*(12), 4812-4819.

Allahyari, M. Z., & Azab, A. J. E. S. w. A. (2018). Mathematical modeling and multi-start search simulated annealing for unequal-area facility layout problem. *91*, 46-62.

Chan, W., Chan, C., Ip, W. J. C., & Engineering, I. (2003). A heuristic algorithm for machine assignment in cellular layout. *44*(1), 49-73.

Derakhshan Asl, A., Wong, K. Y., & Tiwari, M. K. J. I. J. o. P. R. (2016). Unequal-area stochastic facility layout problems: solutions using improved covariance matrix adaptation evolution strategy, particle swarm optimisation, and genetic algorithm. *54*(3), 799-823.

Enea, M., Galante, G., & Panascia, E. J. J. o. I. M. (2005). The facility layout problem approached using a fuzzy model and a genetic search. *16*(3), 303-316.

Farahani, R. Z., & Hekmatfar, M. (2009). *Facility location: concepts, models, algorithms and case studies*: Springer.

García-Hernández, L., Pierreval, H., Salas-Morera, L., & Arauzo-Azofra, A. J. A. S. C. (2013). Handling qualitative aspects in unequal area facility layout problem: an interactive genetic algorithm. *13*(4), 1718-1727.

García-Hernández, L., Salas-Morera, L., Garcia-Hernandez, J., Salcedo-Sanz, S., & de Oliveira, J. V. J. E. S. w. A. (2019). Applying the coral reefs optimization algorithm for solving unequal area facility layout problems. *138*, 112819.

Hasda, R. K. (2017). *Contribution to the optimization of Unequal Area Rectangular Facility Layout Problem.* Ecole centrale de Nantes,

Hosseini-Nasab, H., & Emami, L. J. I. J. o. P. R. (2013). A hybrid particle swarm optimisation for dynamic facility layout problem. *51*(14), 4325-4335.

Hosseini-Nasab, H., Fereidouni, S., Ghomi, S. M. T. F., & Fakhrzad, M. B. J. T. I. J. o. A. M. T. (2018). Classification of facility layout problems: a review study. *94*(1-4), 957-977.

Kang, S., & Chae, J. J. E. S. w. A. (2017). Harmony search for the layout design of an unequal area facility. *79*, 269-281.

Kim, J.-G., & Kim, Y.-D. J. I. J. o. P. R. (2000). Layout planning for facilities with fixed shapes and input and output points. *38*(18), 4635-4653.

Kulturel-Konak, S., Smith*, A., & Norman, B. J. I. J. o. P. R. (2004). Layout optimization considering production uncertainty and routing flexibility. *42*(21), 4475-4493.

Liu, J., Zhang, H., He, K., & Jiang, S. J. E. S. w. A. (2018). Multi-objective particle swarm optimization algorithm based on objective space division for the unequal-area facility layout problem. *102*, 179-192.

Mazinani, M., Abedzadeh, M., & Mohebali, N. J. T. I. J. o. A. M. T. (2013). Dynamic facility layout problem based on flexible bay structure and solving by genetic algorithm. *65*(5-8), 929-943.

Meller, R. D., & Gau, K.-Y. J. J. o. m. s. (1996). The facility layout problem: recent and emerging trends and perspectives. *15*(5), 351-366.

Montreuil, B., Venkatadri, U., & Donald Ratliff, H. J. I. t. (1993). Generating a layout from a design skeleton. *25*(1), 3-15.

Nahar, S., Sahni, S., & Shragowitz, E. (1986). *Simulated annealing and combinatorial optimization.* Paper presented at the 23rd ACM/IEEE Design Automation Conference.

Norman, B. A., Smith, A. E. J. C., & Research, O. (2006). A continuous approach to considering uncertainty in facility design. *33*(6), 1760-1775.

Ripon, K. S. N., Glette, K., Khan, K. N., Hovin, M., Torresen, J. J. S., & Computation, E. (2013). Adaptive variable neighborhood search for solving multi-objective facility layout problems with unequal area facilities. *8*, 1-12.

Rosenblatt, M. J., & Kropp, D. H. J. I. t. (1992). The single period stochastic plant layout problem. *24*(2), 169-176.

Singh, S. P., & Sharma, R. R. J. T. I. J. o. A. M. T. (2006). A review of different approaches to the facility layout problems. *30*(5-6), 425-433.

Turanoğlu, B., & Akkaya, G. J. E. S. w. A. (2018). A new hybrid heuristic algorithm based on bacterial foraging optimization for the dynamic facility layout problem. *98*, 93-104.

Ulutas, B. H., & Kulturel-Konak, S. J. E. S. w. A. (2012). An artificial immune system based algorithm to solve unequal area facility layout problem. *39*(5), 5384-5395.

Van Laarhoven, P. J., & Aarts, E. H. (1987). Simulated annealing. In *Simulated annealing: Theory and applications* (pp. 7-15): Springer.

Zhu, T., Balakrishnan, J., Cheng, C. H. J. I. I. S., & Research, O. (2018). Recent advances in dynamic facility layout research. *56*(4), 428-456.