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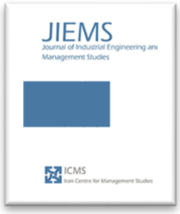

A two-objective mathematical model for solving the facility layout problem using fuzzy goal programming and Artificial Bee Colony optimization

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Abstract

The facility layout problem (FLP) aims to find the location of the facilities so that the departments do not overlap and the desired goals are optimized. The feasibility of proposed solutions in actual conditions is rarely considered in previous studies. This research proposes a two-objective mathematical programming model for solving the FLP to minimize the material handling cost and maximize the total closeness rating between departments, considering the limitations of space and allocable area. The objective functions are aggregated using the fuzzy goal programming approach. Due to the nonlinearity of the proposed model, an algorithm based on the Artificial Bee Colony (ABC) has also been developed to solve the model. The proposed method has been simulated in MATLAB on small, medium, and large samples containing 15, 50, and 100 departments respectively, and the results were compared with that of the PSO. The related aggregated objective function value was obtained as 0.845, 0.837, and 0.836 by the proposed method, and 0.809, 0.789, and 0.839 by the PSO algorithm. Respectively, the computation times were calculated as 15.21, 24.37, and 36.32 seconds in the proposed method, where the PSO obtained the best solutions in 18.22, 32.08, and 46.17 seconds for solving the sample problems. Hence, the calculation results show that the proposed method has a faster calculation time than the PSO and performs better in small and medium examples. Besides, a small variance of obtained solutions in 50 different runs, revealed a high stability of the proposed method.

Keywords: Facility layout problem, Material handling cost, Fuzzy goal programming, Artificial bee colony algorithm, Particle swarm optimization.

Paper Type: Original Research

1. Introduction

The facility layout problem (FLP) is one of the critical issues in industrial engineering that aims to locate the departments in the factory. One of the influential factors in the performance of a production system is the location of the facilities, and much research has been done in this field to consider different conditions. Arrangement of machinery refers to the way production facilities are placed next to each other, which has been considered in production industries. In general, the FLP deals with the layout of facilities, the arrangement of the physical components of a production or service system, and the interaction between departments. Proper arrangement makes the flow of materials in the factory smooth, reduces half-finished products and total production time, and increases the efficiency of the entire production system. Since the cost of material flow takes 20 to 50 percent of the total operating costs and 15 to 70 percent of the cost of a product (Tompkins et al., 2010), a suitable arrangement can save 10 to 30 percent (Paes, 2017). An efficient layout in the factory can create a coordinated flow between the facilities and help to perform the operations that depend on the workflow(Ulutas & Islier, 2015). The dynamic production environment is growing and increasing due to rapid changes in business conditions. To be in sync with these conditions, the arrangement of facilities should be adaptable to these changes. Among the conditions that can be examined are the type of representation of the problem space and the nature of the data used over time (Goncalves, 2015). Due to the rapid changes in commercial environments, dynamic industrial environments are prone to many ups and downs. To be included in the rhythm of these changes, the arrangement of facilities should be compatible with the changes. Due to the various issues in this field, researchers have differing views on the precise and standard definition of layout issues. Koopmans and Beckman are among the first to consider the arrangement concept a common industrial issue that aims to determine the configuration and location of facilities to minimize the cost of transporting materials between them. Xu and Song (2015) defined the layout design problem as determining relative locations and allocating available space to facilities. In their review study, Anjos and Viera (2017) investigated the mathematical programming approaches for solving the FLP. Some researchers consider the layout problem an optimization problem that tries to create efficient layouts by considering the material transportation system and

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various interactions between the facilities when designing the layout. Layout design includes planning, designing, improving, and implementing systems consisting of the establishment plan and the material transportation system to maximize efficiency and spatial desirability (Ulutas & Islier, 2015). Liu et al. (2022a) presented a new method to solve the facility layout problem with two objectives: material handling cost and proximity rank. They used a new approach to control the non-overlapping constraint defined by implementing the gradient method. In their research, Helber et al. (2016) and Tongur et al. (2020) solved the facility layout problem in large-scale hospitals using meta-heuristic algorithms. The main objective of the hospital facility layout problem was to place polyclinics, laboratories, and radiology units in a predetermined range to minimize the cost of moving patients and place mutual units of healthcare workers close to each other. In their research, Besbes et al. (2019) presented a method to solve the facility layout problem using a genetic algorithm and A* search to minimize the cost of transporting materials subject to production constraints. Liu et al. (2020b) presented an improved algorithm for solving the single-row facility layout problem to minimize material handling costs. Chen et al. (2019) discussed optimal facility layout planning for an automated guided vehicle-based prefab system inspired by the cross-learning method of the Toyota Production System industry from prefab factories in the construction industry. This research aims to minimize production time and maximize the use of the workstation. Wei et al. (2019) presented a method to optimize the layout planning of the manufacturing and production system based on the chaotic genetic algorithm. Friedrich et al. (2018) presented a method to solve the facility layout problem with input and output locations based on the contour distance. They used a parallel cutting tree based on a heuristic method to solve the facility design problem, including locating material access points. Secchin et al. (2018) presented an improved integer programming model for a two-line arrangement of facilities to minimize the total cost of material transportation in devices. Jannat et al. (2010) used a genetic algorithm to solve a multi-objective arrangement of facilities problem. Denes and Zarabi (2018) used graph theory and shortest path algorithms to solve the facility location problem. Rauf Moghadam et al. (2017) presented an adaptive genetic algorithm to optimize the problem of unequal facility arrangement. The authors improved the genetic algorithm and developed it into an adaptive genetic algorithm, in which the mutation operator is applied only when the degree of similarity of chromosomes in each population reaches a specific limit. Mousavi et al. (2017) used the Ant Colony Optimization (ACO) meta-heuristic algorithm to solve the problem of the two-line arrangement of facilities. Khaje Mahaleh et al. (2016) used a hybrid algorithm to solve the dynamic facility arrangement problem. Mousavi et al. (2016) solved the single-line facility arrangement problem by using the bat meta-heuristic algorithm. In their research, Khorshidvand et al. (2021) proposed a multi-objective two-staged model for a closed-loop supply chain system and used a fuzzy approach for modeling the missed workdays and justified related fuzzy membership functions. Jiang et al. (2023) presented a two-objective model to reduce material transfer costs and handling costs and solved it using a multi-objective simulation annealing method. A review of previous work shows that the constraint of available allocatable space for locating the departments needs to be considered in previous research. Besides, the desired closeness rating of the departments is rarely considered. In this research, a linear programming model for solving the FLP with two objective functions, including maximizing the total closeness rating of the departments and minimizing the total material handling cost, considering the space limitations, including the total available area and the minimum vertical/horizontal distance between departments is presented. Due to the computational complexity and non-linearity of the proposed model, an algorithm based on the Artificial Bee Colony (ABC) optimization method has been developed to solve the model. The objective functions are aggregated using the fuzzy goal programming approach, and the proposed model is revised to a single-objective model. The rest of the paper is organized as follows: The second section describes the materials and methods, including the definition of the parameters, variables, objective functions, constraints, and aggregating the objective functions. The simulation results are discussed in section 3. The fourth section deals with the research conclusions.

2. Materials and Methods

In this section, the components of the proposed model and the aggregation of the objective functions have been discussed

2.1. Assumptions

The assumptions considered in the proposed model are as follows:

- The length and width of each department are precisely known.
- The height of the workshop is very high and does not affect the problem.
- Movement of materials and parts between machines is done on perpendicular lines.
- All departments are rectangular.
- There is no barrier on the factory floor for department allocation.1. What are the most important indicators

2.2. Parameters

The parameters of the proposed model are defined as follows:

n: total number of departments
cij: the cost of material flow transportation between departments i and j
fij: the amount of transfer flow between departments i and j
li: length of department i
bi: width of department i
gh: minimum horizontal distance of two adjacent departments
gv: minimum vertical distance of two adjacent departments
rij: Proximity rank of departments i and j
h: horizontal length of the total available space
v: vertical length of the total available space

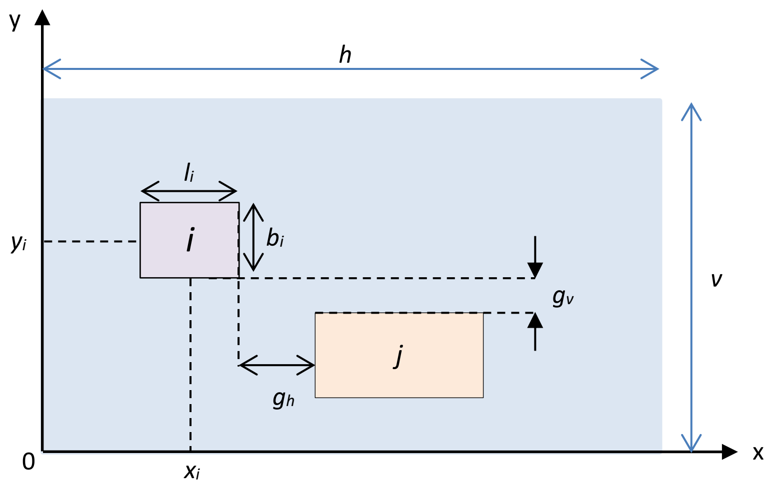

Figure 1. Facility layout diagram

2.3. Decision Variables

The decision variables of the proposed model are defined as follows:

xi: The horizontal coordinate of department i.
yi: The vertical coordinate of department j.
svij: Binary decision variable, 1 if the horizontal coordinates of departments i and j are equal, and 0 otherwise.
shij: Binary decision variable: 1 if the vertical coordinates of departments i and j are equal, and 0 otherwise.
nvij: Binary decision variable: 1 if the departments i and j are horizontally adjacent, and 0 otherwise.
nhij: Binary decision variable: 1 if the departments i and j are vertically adjacent, and 0 otherwise.

2.4. Objective Functions

In this research, the FLP model is constructed considering two objectives as follows:

The first objective function: The first objective is defined as the total material handling cost that is calculated by multiplying the corresponding elements of three n×n matrices: the distance matrix [dij], the material flow matrix [fij], and the cost matrix [cij]. The distance matrix elements change during the optimization process according to the location of departments. The flow and cost matrix elements are given as static input parameters.
The second objective function: The second objective is defined as the total closeness rating of departments that is calculated based on the activity relationship diagram. This diagram represents the desired pairwise proximity departments with specific symbols. In the proposed model, the letters are encoded into numeric values as given in Table (1).

Table 1. Encoding the proximity rating symbols

Code	A	E	I	O	U	X
Description	Absolutely necessary	Especially important	Important	Ordinarily important	Unimportant	Undesirable
Weight	64	32	16	8	1	-64

According to Figure 2, the maximum and minimum distances between departments i and j are calculated using equations 1 and 2 respectively.

$$\text{Max\_Distance}(i, j) = (h - \tfrac{1}{2}bj) + (v - \tfrac{1}{2}li) \quad (1)$$

$$\text{Min\_Distance}(i, j) = \text{Min}\ (gh\ , gv) \quad (2)$$

Considering the six levels of proximity, the stepping interval for evaluating the proximity class of departments i and j is given by equation (3).

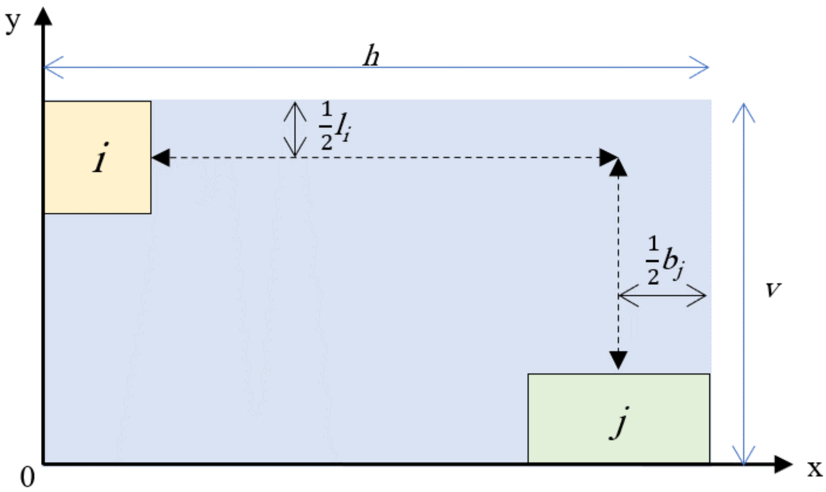

Figure 2. The msximum distance between departments i and j

$$\text{Proximity\_Step}\ (i, j) = \tfrac{1}{6}[\text{Max\_Distance}(i, j) - \text{Min\_Distance}((i, j)] \quad (3)$$

Hence, the proximity class of departments i and j can be calculated using equation (4).

$$\text{Proximity\_Class} = \left\lceil \frac{d_{ij}}{\text{Proximity\_Step(i,j)}} \right\rceil \quad (4)$$

Considering the weight coefficients (given in Table 1) as a row vector, the proximity rank of departments i and j will be obtained by equation (5).

$$r_{ij} = Weigh[Proximity\_Class] \tag{5}$$

2.5. The Mathematical Model

According to the definition of the variables and parameters of the problem, the proposed mathematical model is presented as follows:

$$Min\ \ f_1 = \sum_{i=1}^{n} \sum_{j=1, j\neq i}^{n} c_{ij} \,.\, f_{ij} \,.\, d_{ij} \tag{6}$$

$$Max\ \ f_2 = \sum\nolimits_{i=1}^{n} \sum\nolimits_{j=1, j\neq i}^{n} r_{ij} \tag{7}$$

s.t.

$$d_{ij} = |x_i - x_j| + |y_i - y_j| \qquad \forall\, i, j \;\; i \neq j \tag{8}$$

$$x_i = x_j + M(1 - sv_{ij}) \qquad \forall\, i \tag{9}$$

$$y_i = y_j + M(1 - sh_{ij}) \qquad \forall\, i \tag{10}$$

$$nh_{ij} = sh_{ij}.ch_{ij} \qquad \forall\, i, j \;\; i \neq j \tag{11}$$

$$g_h.ch_{ij} + \left(g_h + \frac{l_i}{2} + \frac{l_j}{2} + 1\right).y_1 \leq d_{ij} \leq (g_h + \frac{l_i}{2} + \frac{l_j}{2}).y_1 \qquad \forall\, i, j \;\; i \neq j \tag{12}$$

$$ch_{ij} + y_1 \leq 1 \qquad \forall\, i, j \;\; i \neq j \tag{13}$$

$$nv_{ij} = sv_{ij}.cv_{ij} \qquad \forall\, i, j \;\; i \neq j \tag{14}$$

$$g_v.cv_{ij} + \left(g_v + \frac{b_i}{2} + \frac{b_j}{2} + 1\right).y_2 \leq d_{ij} \leq (g_v + \frac{b_i}{2} + \frac{b_j}{2}).y_2 \qquad \forall\, i, j \;\; i \neq j \tag{15}$$

$$cv_{ij} + y_2 \leq 1 \qquad \forall\, i, j \;\; i \neq j \tag{16}$$

$$\sum_{i \in A} l_i + (||A|| - 1).g_h \leq h \qquad A = \{i \mid nh_{ij} = 1\} \qquad \forall\, j \tag{17}$$

$$\sum_{i \in B} b_i + (||B|| - 1).g_v \leq v \qquad B = \{i \mid nh_{ij} = 1\} \qquad \forall\, j \tag{18}$$

$$\frac{l_i}{2} \leq x_i \leq v - \frac{l_i}{2} \qquad \forall\, i \tag{19}$$

$$\frac{v_i}{2} \leq y_i \leq h - \frac{v_i}{2} \qquad \forall\, i \tag{20}$$

$$d_{ij}, c_{ij}, f_{ij}, r_{ij}, \geq 0 \qquad \forall\, i, j \tag{21}$$

$$nh_{ij}, ch_{ij}, sh_{ij}, nv_{ij}, cv_{ij}, sv_{ij}, y_1, y_2 \;\in \{0,1\} \qquad \forall\, i, j \tag{22}$$

Relations (6) and (7) express the objective functions of the model. Equation (8) calculates the center-to-center rectilinear distance of departments i and j. Relations (9) and (10) are considered to check whether departments i and j are located on the same row or column, respectively. Relations (11) to (13) inspect whether departments i and j are horizontally neighbors. If yes, the value of the binary variable nhij will be set to 1; otherwise, it

remains 0. Besides, relations (14) to (16) investigate the vertical adjacency of departments i and j. In the case of the positive result, the value of the binary variable nvij will be set to 1.
Equation (17) guarantees that the sum of the length of the neighboring departments does not exceed the length of the entire land. Equation (18) guarantees that the total width of neighboring departments does not exceed the total width of the land. Thus, the feasibility of locating the departments in the available space is guaranteed. This issue has not been considered in previous research. Figure 3 demonstrates the horizontal and vertical allocation feasibility of sample departments. In this figure, A={i, j, k, l}, B={m, k, n}, | | A | | =4, and | | B | | =3. Hence, the constraints (17) and (18) will be satisfied as follows:

$$\text{Eq. 17: } l_i + l_j + l_k + l_l + (4-1) * g_v \leq h$$

$$\text{Eq. 18: } b_m + b_k + b_n + (3-1) * g_h \leq v$$

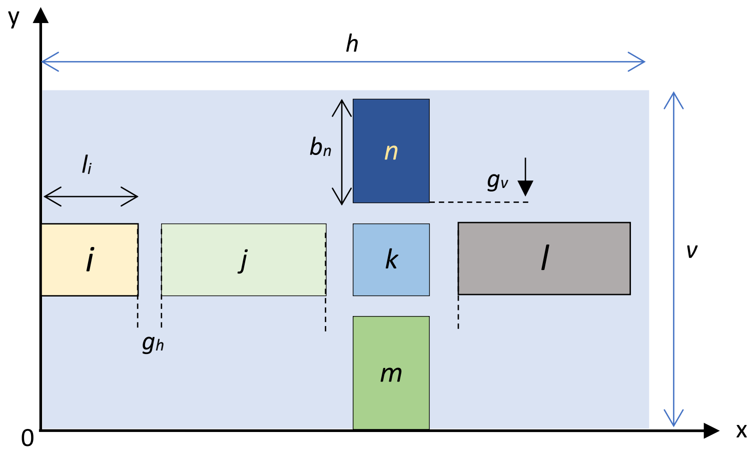

Figure3. Space allocation feasibility constraints

Constraints (19) and (20) guarantee that the coordinates of a department's center are determined so that the entire department will be located inside the feasible area. Constraints (21) and (22) define the model's variables.

2.6. The Goal Programming Approach

The objective functions of the proposed model conflict with each other, and the direction of their changes is different. The optimization of one does not necessarily mean the optimization of the other. In this research, to achieve the best feasible solution satisfying both objective functions, the fuzzy goal programming approach is applied, as explained below.

2.6.1 Fuzzy Membership Function

The first objective function is of the minimization type; the desirability of values larger than its optimal value will decrease while the objective function increases, eventually reaching zero. The reverse condition will be valid for the second objective function of the maximization type. Therefore, the fuzzy membership functions are defined by relations (23) and (24), respectively:

$$u_{f_1}(x) = \begin{cases} 1 & f_1(x) \leq f_1^* \\ 1 - \dfrac{f_1(x) - f_1^*}{d_1} & f_1^* \leq f_1(x) \leq f_1^* + d_{k1} \\ 0 & f_1(x) \geq f_1^* + d_1 \end{cases} \tag{23}$$

$$u_{f_2}(x) = \begin{cases} 0 & f_2(x) \le f_2^* - d_2 \\ 1 - \dfrac{f_2^* - f_2(x)}{d_2} & f_2^* - d_2 \le f_2(x) \le f_2^* \\ 1 & f_2(x) \ge f_2^* \end{cases} \quad (24)$$

Where:

f_k^*: the optimal value of the kth objective function (k=1, 2)

d_k: acceptable deviation from the optimal value of the kth objective function.

Since the first objective function cannot have a value smaller than and the second objective function cannot have a value greater than, the desirability of these points for the decision-maker will be equal to one. The d1 and d2 values are the length of the acceptable interval of the objective functions, and the values outside this interval are unacceptable, and their desirability is equal to zero. The corresponding fuzzy membership functions are depicted in Figure 4. Under the mentioned conditions, these membership functions cannot be defined as triangular, trapezoidal, or Gaussian.

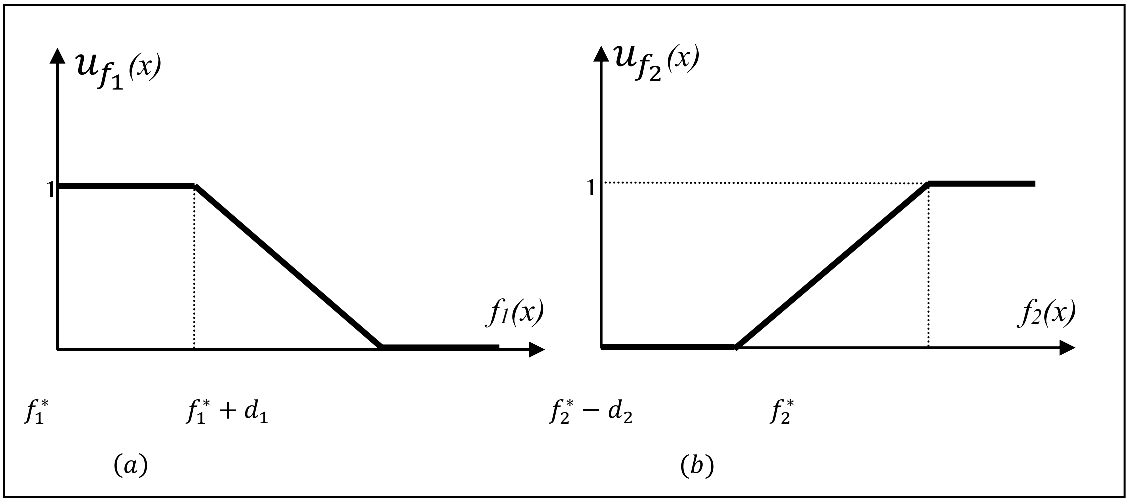

Figure 4. The membership functions: a) objective function f1 b) objective function f2

The values of f_k^* are obtained by solving the model only considering the kth objective function (ignoring the other one) and under all the defined constraints.

2.6.2. Aggregating the Objective Functions

To aggregate the objective functions and convert the proposed model into a single objective, the fuzzy approach provided by Torabi and Hassini (2008) has been used as follows:

$$Max\ \lambda = \gamma.\lambda_0 + (1-\gamma).(w_1.u_{f_1} + w_2.u_{f_2}) \quad (25)$$

Where λ0 is the minimum satisfaction level of the objective functions. This approach, defined as the convex combination of the lower limit (λ0) and the weighted sum of satisfaction of the objective functions, achieves an adjustable balanced solution (Karaboga & Akay, 2009). The relative importance of the kth objective function is determined by hk coefficients, and the decision maker determines its value. In this article, the values of these coefficients are considered equal to 0.5. The coefficient γ also determines the percentage of compensation and the minimum level of satisfaction of the objective functions. Larger values for this coefficient indicate higher importance of achieving a larger minimum for the satisfaction degree of the objective functions. Besides, considering smaller values indicates more importance for the value agreement between the objective functions, regardless of their minimum level of satisfaction. In this research, this coefficient is considered equal to 0.2. Finally, the revised mathematical model is proposed as follows:

$$\text{Max}\ \lambda = \gamma.\lambda_0 + (1-\gamma).(w_1.u_{f_1} + w_2.u_{f_2}) \quad (26)$$

s.t.

$$\lambda 0 \leq \mu_{f_1}(x); \quad (27)$$

$$\lambda 0 \leq \mu_{f_2}(x); \quad (28)$$

Plus equations (3) through (22) (29)

2.7 The ABC Algorithm

Due to the non-linearity of the proposed mathematical model, a meta-heuristic solution method based on the artificial bee colony algorithm has been developed. The honey bee colony algorithm is an optimization algorithm based on swarm intelligence and the intelligent behavior of the bee population, which was presented by Karaboga in 2005 for realistic parameter optimization. The bees of a beehive can spread for kilometers around the hive and search and collect nectar. The difference in the amount of nectar available in each source requires allocating a specific number of bees to collect nectar according to these amounts (Karaboga & Akay, 2009). In the ABC algorithm, the bees include three groups worker bees, guards, and leaders. A honey bee goes to predetermined food sources, a worker bee and a bee that stays in the dancing area to choose a food source, a guard bee, and a random search bee. It is called the onlooker bee [24]. At the first stage of the algorithm, half of the bee population is worker bees, and the other half is onlooker bees. An initial position of food resources is generated when each worker bee is randomly nominated to start foraging. Then, each worker bee determines their nearby food resources according to the equation (30). If the nectar in the new food sources is better than the old sources, the worker bee flies to new food sources (Karaboga & Basturk, 2007).

$$V_{ij} = X_{ij} + \varphi_{ij}(X_{ij} - X_{kj}) \quad (30)$$

Where φij is a random number between (-1,1), Vi is a chosen solution, Xi is the current solution, and Xk is the adjacent solution. After completing the search process, the worker bees transfer the information they have obtained about the food sources to the guard bees. The guard bee examines the nectar-related information from the worker bees and selects the food sources with the most nectar according to equation 31 (Karaboga & Basturk, 2007).

$$p_i = \frac{f_{i_{ti}}}{\sum_{n=1}^{SN} f_{i_{t_i}}} \quad (31)$$

Where $f_{i_{t_i}}$ is the appropriate amount of variable i in the nectar of food sources at position i and SN, the number of food sources is equal to the number of worker bees. One of the guard bees chooses food sources, and each finds a food source near them and calculates the amount of available nectar. The bee can remember the new location and forget the previous one with less nectar. It can even remember the previous situation. A worker bee becomes an explorer when it finds and uses a food source. Any location can be converted into cycles that are considered limited parameters. According to the structure of the proposed model, each flower represents a solution, and the amount(quality) of nectar of each flower indicates the goodness(fitness) of that solution, which is calculated by equation (26). A food source represents the entire solution space, and bees are the random search methods in the problem space. A solution randomly generated by a bee suggests an arrangement for the facility. It may only be feasible if it satisfies all the constraints. The solution's fitness will be calculated if feasible; otherwise, the solution will be omitted. By moving randomly in the solution space, the bees search in the food source and find solutions having more favorable fitness. The structure of a solution is designed as a vector of size n containing ordered pairs (Figure 5). The ith element(pair) of this vector expresses the (xi,yi) coordinates of the ith department at the workshop space.

(x_1,y_1)	(x_2,y_2)	…	(x_n,y_n)

Figure5. The structure of a solution in the proposed ABC

In population-based meta-heuristic methods, the initial population is generated randomly, so some of the generated solutions may be unjustified. In the proposed method, in forming the initial population, each item of a solution is not entirely assigned randomly, and a minimum distance between the center of two adjacent departments is considered to prevent overlapping. This will lead to faster convergence of the algorithm. In each iteration, the best solution found so far is kept and announced as the final solution when the procedure ends.

3. Results

The proposed method is simulated in MATLAB using a personal computer running Windows 10 with a Corei5 processor and 8 GB of RAM. To simulate the proposed model, three numerical scenarios in small-size (example 1), medium-size (example 2), and large-size (example 3) are randomly defined. The specifications and parameters are given in Table (2). The values of the parameters of the model are given in Table 2.

Table 2. Specification of simulated examples

Scenario	Initial Population	# of Department	# of Iterations	h (meter)	v (meter)	li (meter)	vi (meter)
Example 1	50	15	100	100	60	U(3,6)*	U(2,4)
Example 2	75	50	150	300	200	U(4,8)	U(3,5)
Example 3	120	100	200	600	400	U(5,12)	U(4,6)

*U(a,b) is the uniform distribution function

Table 3. The parameter values of the proposed model

Scenario	f_1^*	f_2^*	d_1	d_2	λ_0	γ	w_1	w_2
Example 1	286861	25840	71715.25	6460	0.75	0.3	0.5	0.5
Example 2	3754661	46600	938665.25	11650	0.75	0.3	0.5	0.5
Example 3	12615798	68400	3153949.5	17100	0.75	0.3	0.5	0.5

Each of the examples mentioned in Table (2) has been executed 50 times, and the average calculation time (seconds) and the best-obtained values of f1, f2, and λ are given in Table (4).

Table 4. Simulation results obtained by the proposed method

Scenario	f1	f2	λ	Average computation time (seconds)
Example 1	292411	24860	0.845	15.21
Example 2	3822154	44520	0.837	24.37
Example 3	13126840	66820	0.836	36.32

Figure 6 shows the convergence diagram of λ for the best solution of example 3. According to the diagram, the proposed method is converged at iteration 105, and the final solution has been obtained.

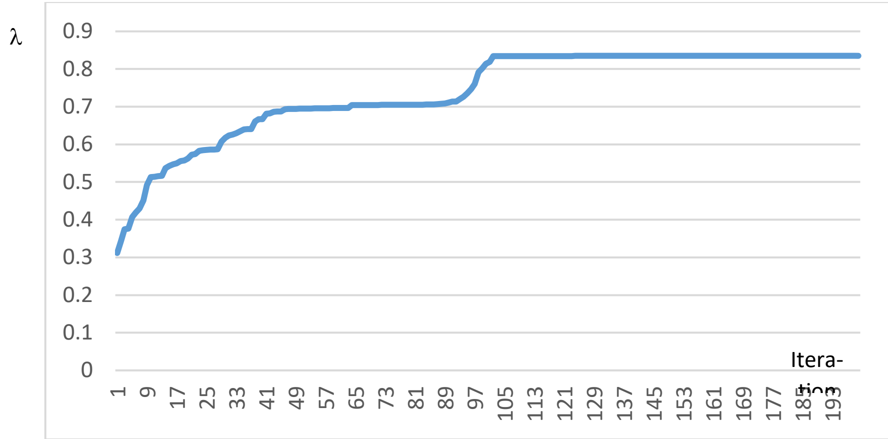

Figure 6. Convergence diagram of the objective function of example 3

Due to the random search nature of meta-heuristic methods, the stability of such methods should be verified. A minor variance of obtained solutions in different runs validates this issue. Figure 7 demonstrates the stability diagram of the proposed method in 50 different executions of Example 3. According to the results, the proposed method obtained the final solution equal to 0.836 in 88% of cases. The variance of the obtained solutions was 0.001282, indicating the high stability of the proposed method.

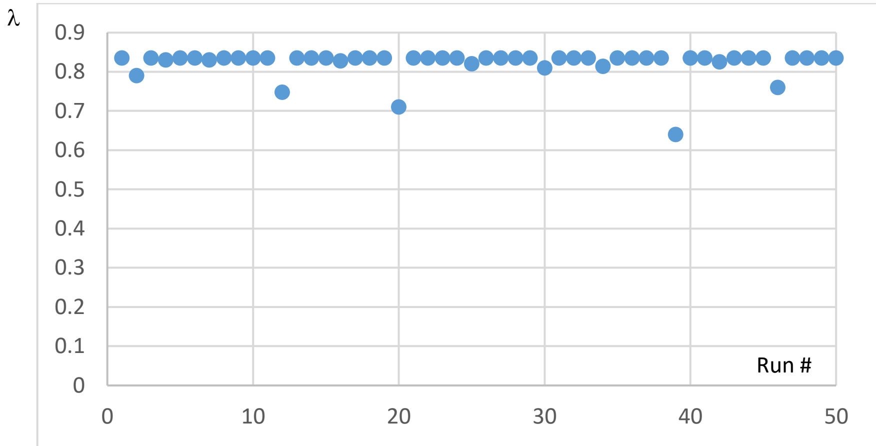

Figure 7. The stability diagram of the proposed method in 50 runs of example 3

The same examples were also simulated in MATLAB using the particle swarm optimization (PSO) method to evaluate the efficiency of the proposed method. The comparison of calculation results is given in Table (5).

Table 5. Simulation results obtained by the PSO method

Scenario	f1	f2	λ	Average computation time (seconds)
Example 1	293500	24310	0.809	18.22
Example 2	3851026	43300	0.789	32.08
Example 3	12794866	65210	0.839	46.17

The performance comparison of the proposed method along with the PSO is depicted in Figure 8.

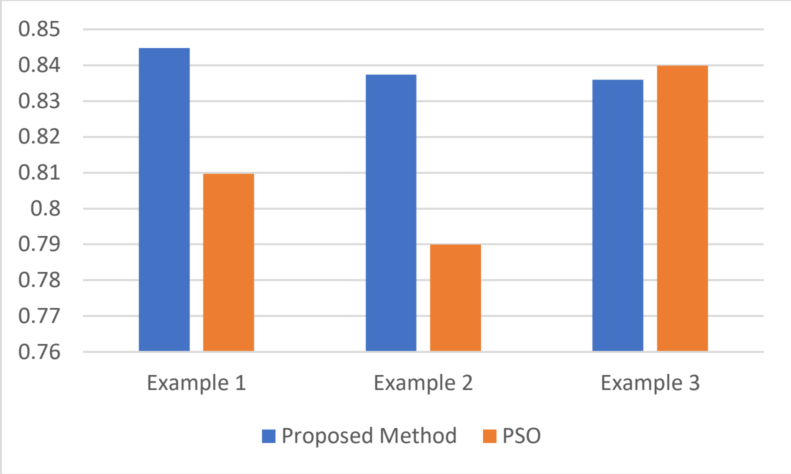

Figure 8. Performance comparison diagram

The comparison of the results reveals the superiority of the proposed method from a computation time point of view. Besides, the proposed method has obtained better results in examples 1 and 2 and slightly worse in example 3.

4. Conclusions

An industrial plant consists of several departments that perform different production operations. To improve the material flow and reduce manufacturing costs, the construction layout of the departments must be analyzed based on technical criteria and management considerations. The facility layout problem deals with determining the optimal location of departments in the factory and considering specific objective function(s). In this research, a two-dimensional facility layout problem was studied, and a linear programming model was proposed to minimize the total material handling cost and maximize the total proximity rate of the departments. The material handling cost is calculated by item-to-item product of flow(from/to), distance, and cost matrices. A minimum vertical/horizontal distance between adjacent departments was considered two constraints to avoid overlapping the departments. Besides, new constraints were considered to guarantee the limitation of locating the departments inside the total available space, which should have been considered in previous studies. To aggregate the objective functions, the fuzzy goal programming approach was used to revise the model to a single objective model. The proposed model was non-linear due to the product of the decision variables in constraints. Hence, a solution algorithm based on the artificial bee colony meta-heuristic was developed and simulated with MATLAB on three sample problems on small, medium, and large scales with 15, 50, and 100 departments respectively. The best solution for the aggregated objective function was obtained as 0.845 for sample 1 in 15.21 seconds, 0.837 for sample 2 in 24.37 seconds, and 0.836 for sample 3 in 36.32 seconds. The simulation results showed that the proposed method can solve the sample examples in an acceptable computational time and have a suitable convergence in reaching the final solution since the maximum iterations needed to solve the large-scale problem was 105. Besides, the quality of obtained solutions in all examples was considerably high since the minimum satisfaction level for both objective functions was more than 83% in all three examples. To evaluate the stability of the proposed method, the largest sample (example 3) was solved 50 times and a slight variance equal to 0.001282 of the solutions obtained in 50 different executions revealed the efficiency and stability of the proposed method. To compare the efficiency of the proposed algorithm, the same examples were also solved using the particle swarm optimization method. The aggregated objective function value was obtained equal to 0.809 for sample 1, 0.789 for sample 2, and 0.839 for sample 3. According to these results, the proposed method showed a better performance in solving small and medium-scale problems, but slightly worse in the large-size example. The calculation times for obtaining the best solutions for the sample problems were 18.22, 32.08, and 46.17 seconds respectively. Thus, the numerical results showed that the proposed method had less computing time for solving all three examples. More computation time in the particle swarm method was probably due to the structural complexity of this method compared to the bee colony algorithm, and it may be reduced by fine-tuning its parameters. Considering the goodness of the obtained solutions, the proposed method has performed better than the particle swarm optimization method in both small and medium-sized examples and slightly worse in the third example. The future studies are as suggestions as follows:

Considering different and more objective functions

Considering the FLP in 3D arrangement

Using other meta-heuristic algorithms

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