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ORIGINAL ARTICLE

Dynamic facility layout problem based on flexible bay structure and solving by genetic algorithm

Mostafa Mazinani · Mostafa Abedzadeh · Navid Mohebali

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Abstract Finding positions of departments on the plant floor for multiple periods while minimizing the sum of material handling and rearrangement costs is the base consideration of dynamic facility layout problems (DFLP). In this paper, a new kind of DFLP using flexible bay structure is studied. In a plant layout, based on flexible bay structure, departments are assigned to parallel bays in a plant floor. Departments could be free oriented and may have unequal areas as well as a mixed integer programming formulated to find optimal solutions. Due to complexity, only small-size problems could be solved in logical time while using exact methods. Therefore, a genetic algorithm (GA) was proposed to solve this optimization problem. This method was tested on some test problems of the DFLP literature. The results show the effectiveness of the proposed algorithm.

Keywords Dynamic facility layout problem · Continuous layout · Flexible bay structure · Unequal area · Genetic algorithms

1 Introduction

The dynamic facility layout problem extends the static facility layout problem (SFLP) by considering changes in material flow between departments over planning horizon. This issue may lead to rearrangement of layout. In real conditions, SFLP will be suitable if material flow does not change for a long time and by considering that most of the working places nowadays are changing, so study of the dynamic facility layout problems (DFLP) will be necessary.

The fundamental DFLP is due to material flow changes between departments over planning horizon. Planning horizon is divided to several periods which are defined by week, month, or year. The solution for the SFLP is a single layout; but for the DFLP, it is a series of layouts (layout plan) with each layout associated with a specific period. Therefore, the total cost of a layout plan consists of the sum of the material handling costs for all periods and the sum of the rearrangement costs [1].

For each period, the DFLP can be considered as an SFLP and each SFLP is solved independently. Although created series of layouts may have lower material handling cost, excess cost of rearrangement would be uneconomical (e.g., heavy machines may need to be moved). So the following two cost balances should always be considered [2]:

- Extra cost of material flows will exist when rearrangement is not done; which may seem necessary to be done.
- Extra rearrangement cost is due to facility moving which may cause stoppage of production line, need to special tools, manpower, and so on.

So the DFLP includes selecting a static layout for each period and then deciding whether to change to a different layout in the next period or not. If the rearrangement costs are rather low, the layout configuration would tend to change more often to retain material handling efficiency. The reverse is true for high rearrangement costs [2].

Usually, in DFLP literature, the objective function minimizes the sum of the costs of material handling and rearrangement for all periods. Usually, the difference between objective function is related to rearrangement costs depending on the problem. The department rearrangement costs

M. Mazinani (✉) · M. Abedzadeh
Department of Industrial Engineering,
K.N. Toosi University of Technology,
Tehran, Iran
e-mail: mazinani.ie@gmail.com

N. Mohebali
Department of Industrial Engineering,
Amirkabir University of Technology,
Tehran, Iran

may be divided into two categories: fixed and variable costs [2]. Fixed costs are defined as costs which do not depend on how much departments have been rearranged. In contrast, variable costs are based on the distance the departments are transported and the increase or decrease in department sizes. In most of the papers available in DFLP literature, they use fixed rearrangement costs.

Facility layout problem is categorized as NP hard problems [3]. Its complexity increases due to having multiple periods (multiple periods cause an increase in solution space of the problem). For the purpose of solving such a problem in a reasonable time and finding a good quality solution, it is necessary to choose a powerful metaheuristic algorithm [4–20]. Nowadays, genetic algorithms are used in many fields because of the capability to search parallel to the complicated spaces and preventing from achieving the local optimal solution. In recent years, genetic algorithms have been developed to solve the facility layout problems [8–20]. In this paper, genetic algorithm is used for solving the dynamic facility layout problem with flexible bay structure. In flexible bay structure (FBS), a problem is allocated to parallel bays with different widths.

The structure of this paper is as follows: Section 2 provides a literature review of the DFLP and FBS. In Section 3, a mathematical formulation for DFLP using FBS with unequal area departments is presented. In Section 4, a genetic algorithm is proposed for DFLP. In Section 5, case problems and parameter are mentioned and the settings which are used to test the proposed algorithm are discussed. Finally, conclusions are drawn in Section 6.

2 Literature review

Mathematics formulation to solve DFLP can be based on several types of models, which allow the complex relationships between the different elements involved in a layout problem to be expressed. Depending on the manner in which the problem is formulated, that is, discrete or continuous. Rosenblatt [21] was the first to introduce DFLP. He used two heuristic methods based on dynamic programming to solve DFLP. Rosenblatt considered equal areas for departments and used discrete layout.

In discrete layout, the problem usually considered is a quadratic assignment problem (QAP) where a plant floor is divided into rectangular blocks with the same area and shape, and each block is assigned to one special facility. If the facilities have different areas, then they occupied several blocks [22, 23]. Generally, this layout design was used for DFLP. Regarding discrete layout, many researches have been done, some of them are as follows:

Conway and Venkataramanan [10] used a genetic algorithm to solve DFLP. Balakrishnan and Cheng [11] investigated Convey's genetic algorithm and improved it. Baykasoglu and Gindy [24] have developed a simulated annealing algorithm (SA) for DPLP. Using the test problems, they showed that their algorithm performed better than the genetic algorithms (GAs) of Conway and Venkataramanan [10] and Balakrishnan and Cheng [11]. Balakrishnan et al. [12] presented a hybrid genetic algorithm to solve DFLP. Dynamic programming is then used in the crossover operator to create offspring and the CRAFT is used in mutation. McKendall et al. [1] presented two simulated annealing heuristics for DFLP. The first heuristic is a direct adaptation of SA to solve DFLP. The second SA heuristic is a modification of the first SA, with added look-back strategy.

Due to special limitation of discrete models, some of the authors believe that continuous models are suitable. Discrete models are not suited to represent the exact position of facilities in the plant floor and also not able to make proper model due to some special constraints such as orientation of facilities, empty space between facilities, and input/output points. In continuous space, equipments stayed in continuous plant in a way they do not have any overlap. These problems often formulated mixed integer linear programming (MILP). Very few works have been done on the DFLP with a continuous representation [22]. Montreuil and Venkatadri [25] presented the first formulation for the DFLP with unequal area departments and different shape. In their model, positions of departments in the final layout are known. Also, the department areas increase in sequential periods, and the boundaries of each department in each period should be within the boundaries of the same department in the next period. The mathematical formulation does not require binary variables, because the relative positions of pairs of departments are known. Therefore, large problems can be solved to optimum. This linear programming model was improved by Montreuil and Laforge [26] by relaxing the assumptions that the department areas increase in sequential periods and that the boundaries of each department in each period should be within the boundaries of the same department in the next period. Similar to Montreuil and Venkatadri [25], the mathematical formulation is linear, since the relative positions of departments in each probable future are specified by the designer and fixed rearrangement costs are not considered.

Lacksonen [27] presented a two-stage heuristic for solving the DFLP with unequal area departments. In the first stage, all departments are assumed to have equal sizes and the DFLP with equal area departments is solved by the cutting plane heuristic presented in Lacksonen and Enscore [28]. In second stage, for every time period, a static unequal area facility layout problem is solved as a modification of the MILP by Montreuil [29]. Second stage includes constraints, which ensure that the departments and time periods, which are not rearranged in first stage, are not rearranged in second stage as well. Dunker et al. [13] extended the GA presented in Dunker et al. [14] to solve the DFLP with unequal area departments. The authors used a hybrid approach, which combined dynamic programming with a genetic algorithm. Dynamic programming is used to evaluate the fitness of each gene.

Dong et al. [30] considered DFLP under dynamic business environment, in which new machines may be added into or old machines may be removed from the plant. They used an auction algorithm to solve the shortest path problem and a shortest path based on a simulated annealing algorithm is presented to solve the optimization problem. McKendall et al. [31] used boundary search technique that places departments along the boundary of existing departments to solve DFLP with unequal areas. They used tabu search (TS) heuristics to improve the solution.

In literature review on the layout problem, some researchers have been using an interesting approach under the title of flexible bay structure to represent the scheme of layout. This approach, which limited the state of the continuous layout problem for the first time, was proposed by Tong [32] in 1991. In layout based on flexible bay structure, plant floor is divided to horizontal or vertical bays in which the width of each bay is flexible and dependent on the numbers of departments that are located in that bay (width of each bay is gained from the division result of areas of departments, which are assigned to that bay by the minimum sides of plant floor). In addition, the number of bays and departments that are set in each bay are changeable (flexible). It should be mentioned that in problems based on flexible bay structure due to control departments' shape, the factor of the maximum aspect ratio is used. After propounding the idea of flexible bay structure, Tate and Smith [15] used the genetic algorithm for solving the dynamic facility layout problems based on flexible bay structure. They showed problem solutions by two chromosomes. The first chromosome was the permutation of departments, which showed a sequence of departments inside each bay. The second chromosome contained information about the number of bays and break points.

Arapoglu et al. [16] have used a genetic algorithm for solving FBS with considering input and output points. Kulturel-Konak et al. [33] used tabu search algorithm for solving FBS problem. Enea et al. [17] used a genetic algorithm for solving the layout problem with FBS when demand production is variable. Hence, fuzzy number was used in order to compute material flow. Konak et al. [34] presented an MILP which is the first exact approach to find the optimal FBS solution. They have tightened their model by using constraints, which are consisted of removing symmetric solutions, increase in lower bound for the problem, and reducing model degeneracy. Then they solved problems up to 14 departments exactly. Norman et al. [18] considered facility layout problem under the condition that the determination of non-existence of a material handling cost in a continuous scale used mathematical expectation and standard deviation related to prediction of production, and for solving, used genetic algorithm basing its coding on random numbers.

Aiello et al. [19], considering multicriterions, studied layout problem in multi-objective condition. They solved layout problem based on flexible bay structure by using genetic algorithm and electre method, and considering material handling cost criterions, required adjacency scale, required distance scale, and shape ratio. They eliminated shape ratio limitations by using shape ratio objective function. In different steps of the genetic algorithm, it always produces feasible layouts and do not need a specific strategy in the encounter with shape ratio constraint. Kulturel-Konak et al. [35] considered flexible bay structure for facility relayout problem and solved it by TS algorithm.

Alagoz et al. [20] have considered assumptions such as passage way, and input and output points for FBS problem, and have used a genetic algorithm for solving it. In 2010, Wong and Komarudin [36] used ant system algorithm (ASA) and Kulturel-Konak and Konak [37] used ant colony optimization (ACO) for solving the layout problem with flexible bay structure. They have considered the empty place by using dummy departments for this problem.

Considering that no research is reported on the flexible bay structure being used in the field of dynamic facility layout, and because of the desired qualities that layout based on flexible bay structure has, this paper aims to extend research on flexible bay structure in the district of dynamic facility layout. In addition, a genetic algorithm is proposed for solving it.

This paper is used to construct a solution for DFLP based on FBS under the following assumptions:

1. Maximum aspect ratio is used for the purposes of controlling department shapes.
2. Departments may have unequal areas. In other words, they are either square or rectangular in shape.
3. Department areas are fixed for each period but may vary from one period to another.
4. Departments orientation can be changeable (i.e., departments may be either horizontally or vertically oriented)
5. The layout for each period uses the continuous representation of the plant floor.
6. Departments should assign in parallel bays with varying widths. If a department is assigned to a bay, it must be completely filled.
7. Objective function minimizes the sum of the costs of material handling and rearrangement. The rearrangement costs include fixed and variable costs.

3 A mathematical formulation for DFLP

In this section, an MILP formulation based on FBS for the DFLP with unequal area is presented, which generate a continuous layout and departments should only assign in parallel bays with varying widths. A similar formulation for

SFLP is presented by Konak et al. [34], although their formulation is static. First, the notation is given as follows.

Indexes

$t = 1, 2, ..., T$	where T is the number of periods
$i, j = 1, 2, ..., N$	where N is the number of departments
$k = 1, 2, ..., B_t$	where k is the number of bays

Parameters

W	Width of the plant floor along the x-axis
H	Length of the plant floor along the y-axis
B_t	Maximum number of the parallel bays in period t
a_{ti}	Area requirement of department i in period t
α_{ti}	Aspect ratio of department i in period t
$l_{ti}^{\max} = \min\{W, \sqrt{\alpha_{ti} a_{ti}}\}$	Maximum permissible side length of department i in period t
$l_{ti}^{\min} = \sqrt{\frac{a_{ti}}{\alpha_{ti}}}$	Minimum permissible side length of department i in period t
F_{tij}	Amount of material flow from department i to department j in period t
$F'_{tij} = F_{tij} + F_{tji}$	Amount of material flow between departments i and j in period t (upper triangular matrix)
C_{tij}	The cost for moving per unit material a unit distance between departments i and j in period t
A_{ti}	Rearrangement fixed cost of shifting department i at the beginning period t
R_{ti}	Rearrangement variable cost of shifting department i at the beginning period t

Variables

w_{tk}	Width (the length in the x-axis direction) of bay k in period t
h_{tik}	Height of department i in bay k in period t
l_{ti}^{y}	Height (the length in the y-axis direction) of department i in period t
(x_{ti}, y_{ti})	Coordinates of the centroid of department i in period t
$d_{tij}^{x} = \lvert x_{ti} - x_{tj}\rvert = d_{tij}^{+x} + d_{tij}^{-x}$	Horizontal distance between the centers of departments i and j in period t
$d_{tij}^{y} = \lvert y_{ti} - y_{tj}\rvert = d_{tij}^{+y} + d_{tij}^{-y}$	Vertical distance between the centers of departments i and j in period t
$p_{ti}^{x} = \lvert x_{ti} - x_{t-1,i}\rvert = p_{ti}^{+x} + p_{ti}^{-x}$	The amount of horizontal movement for department i from period $t-1$ to t
$p_{ti}^{y} = \lvert y_{ti} - y_{t-1,i}\rvert = p_{ti}^{+y} + p_{ti}^{-y}$	The amount of vertical movement for department i from period $t-1$ to t

$$z_{tik} = \begin{cases} 1 & \text{if department } i \text{ is assigned to bay } k \text{ in period } t \\ 0 & \text{otherwise} \end{cases}$$

$$\delta_{tk} = \begin{cases} 1 & \text{if bay } k \text{ is occupied in period } t \\ 0 & \text{otherwise} \end{cases}$$

$$s_{tij} = \begin{cases} 1 & \text{if department } i \text{ is above department } j \text{ in the same bay in period } t \\ 0 & \text{otherwise} \end{cases}$$

$$r_{ti} = \begin{cases} 1 & \text{if department } i \text{ is rearranged at the beginning of period } t \\ 0 & \text{otherwise} \end{cases}$$

In the model description, without loss of generality, the long side of the plant floor is along the horizontal axis direction, and bays are assumed to run vertically. Also, the coordinates of the southwest corner of the plant floor are (0, 0).

The mixed integer programming (MIP) formulation for the flexible bay structure problem is given as follows:

$$\min Z = \sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{j>i}^{N} C_{tij}F'_{tij}\left(d_{tij}^{+x} + d_{tij}^{-x} + d_{tij}^{+y} + d_{tij}^{-y}\right) + \sum_{t=2}^{T}\sum_{i=1}^{N} A_{ti}r_{ti} + \sum_{t=2}^{T}\sum_{i=1}^{N} R_{ti}\left(p_{ti}^{+x} + p_{ti}^{-x} + p_{ti}^{+y} + p_{ti}^{-y}\right) \quad (1)$$

Subject to:

$$x_{ti} - x_{tj} = d_{tij}^{+x} - d_{tij}^{-x} \qquad \forall t, i, j > i \quad (2)$$

$$y_{ti} - y_{tj} = d_{tij}^{+y} - d_{tij}^{-y} \qquad \forall t, i, j > i \quad (3)$$

$$x_{ti} - x_{t-1,i} = p_{ti}^{+x} - p_{ti}^{-x} \quad \forall i, t > 1 \quad (4)$$

$$y_{ti} - y_{t-1,i} = p_{ti}^{+y} - p_{ti}^{-y} \quad \forall i, t > 1 \tag{5}$$

$$\sum_k z_{tik} = 1 \quad \forall t, i \tag{6}$$

$$w_{tk} = \frac{1}{H} \sum_i z_{tik} a_{ti} \quad \forall t, k \tag{7}$$

$$l_{ti}^{\min} z_{tik} \leq w_{tk} \leq l_{ti}^{\max} + W(1 - z_{tik}) \quad \forall t, i, k \tag{8}$$

$$x_{ti} \geq \sum_{j \leq k} w_{tj} - 0.5 w_{tk} - (W - l_{ti}^{\min})(1 - z_{tik}) \quad \forall t, i, k \tag{9}$$

$$x_{ti} \leq \sum_{j \leq k} w_{tj} - 0.5 w_{tk} + (W - l_{ti}^{\min})(1 - z_{tik}) \quad \forall t, i, k \tag{10}$$

$$\frac{h_{tik}}{a_{ti}} - \frac{h_{tjk}}{a_{tj}} - \max\left\{\frac{l_{ti}^{\max}}{a_{ti}}, \frac{l_{tj}^{\max}}{a_{tj}}\right\}(2 - z_{tik} - z_{tjk}) \leq 0 \ \forall t, k, i, j > i \tag{11}$$

$$\frac{h_{tik}}{a_{ti}} - \frac{h_{tjk}}{a_{tj}} + \max\left\{\frac{l_{ti}^{\max}}{a_{ti}}, \frac{l_{tj}^{\max}}{a_{tj}}\right\}(2 - z_{tik} - z_{tjk}) \geq 0 \quad \forall t, k, i, j > i \tag{12}$$

$$\sum_i h_{tik} = H\delta_{tk} \quad \forall t, k \tag{13}$$

$$l_{ti}^{\min} z_{tik} \leq h_{tik} \leq l_{ti}^{\max} z_{tik} \quad \forall t, i, k \tag{14}$$

$$\sum_k h_{tik} = l_{ti}^{y} \quad \forall t, i \tag{15}$$

$$y_{ti} - 0.5 l_{ti}^{y} \geq y_{tj} + 0.5 l_{tj}^{y} - H(1 - s_{tij}) \quad \forall t, i, j \neq i \tag{16}$$

$$s_{tij} + s_{tji} \leq 1 \quad \forall t, i, j > i \tag{17}$$

$$s_{tij} + s_{tji} \geq z_{tik} + z_{tjk} - 1 \quad \forall t, k, i, j > i \tag{18}$$

$$0.5 l_{ti}^{y} \leq y_{ti} \leq H - 0.5 l_{ti}^{y} \quad \forall t, i \tag{19}$$

$$x_{ti} - x_{t-1,i} \leq W r_{ti} \quad \forall i, t > 1 \tag{20}$$

$$x_{t-1,i} - x_{ti} \leq W r_{ti} \quad \forall i, t > 1 \tag{21}$$

$$y_{ti} - y_{t-1,i} \leq H r_{ti} \quad \forall i, t > 1 \tag{22}$$

$$y_{t-1,i} - y_{ti} \leq H r_{ti} \quad \forall i, t > 1 \tag{23}$$

$$l_{ti}^{y} - l_{t-1,i}^{y} \leq H r_{ti} \quad \forall i, t > 1 \tag{24}$$

$$l_{t-1,i}^{y} - l_{ti}^{y} \leq H r_{ti} \quad \forall i, t > 1 \tag{25}$$

$$x_{ti}, y_{ti}, l_{ti}^{y}, w_{tk}, h_{tik}, d_{tij}^{+x}, d_{tij}^{-x}, d_{tij}^{+y}, d_{tij}^{-y}, p_{ti}^{+x}, p_{ti}^{-x}, p_{ti}^{+y}, p_{ti}^{-y} \geq 0 \quad \forall t, i, j, k \tag{26}$$

$$z_{tik} = 0 \ or \ 1, \delta_{tk} = 0 \ or \ 1, s_{tij} = 0 \ or \ 1, r_{ti} = 0 \ or \ 1 \quad \forall t, i, j, k \tag{27}$$

The first term in objective function (1) is used to obtain material handling costs, the second term is for fixed costs of rearrangement, and the third term is for variable costs of rearrangement. Constraints (2)–(5) is the linearization the absolute value term in the rectilinear distance function. value term in the rectilinear distance function. For this purpose, two forms are usually used, as explained by the following example.

The absolute values in $|x_{ti} - x_{tj}|$ can be linearized either as $x_{ti} - x_{tj} \leq d_{tij}^{x}$ and $x_{tj} - x_{ti} \leq d_{tij}^{x}$ or as $d_{tij}^{x} = d_{tij}^{+x} + d_{tij}^{-x}$ and $x_{ti} - x_{tj} = d_{tij}^{+x} - d_{tij}^{-x}$ where $d_{tij}^{+x}, d_{tij}^{-x} \geq 0$. In this paper, the latter formulation is used.

Constraints (6)–(19) are so similar to constraints in Konak et al. [34]. Constraint (6) ensures that each department is assigned to a single bay. Constraints (7) and (8) calculate the width of each bay based on the departments assigned to each bay. Constraint sets (9) and (10) determine the positions of the departments centroid along the horizontal axis. Constraints (7), (9), and (10) also ensure that the departments are within the boundaries of the plant floor along the horizontal axis. Constraints (11)–(18) are used to determine the position of the departments centroid along the vertical axis. These constraints also ensure that the departments do not overlap in the vertical-axis direction. Constraint (19) ensures that the departments are within the boundaries of the plant floor along the vertical-axis. Constraints (20)–(25) ensure that the department has the same values of length, width, and center coordinates in any two sequential periods in which the department is not rearranged. Finally, restrictions on the variables are given in constraints (26) and (27).

4 Genetic algorithm for the DFLP base on FBS

The genetic algorithms are metaheuristic methods to solve problems based on evolution mechanisms and nature of gens. The main idea in this regard was introduced by Holland [38]

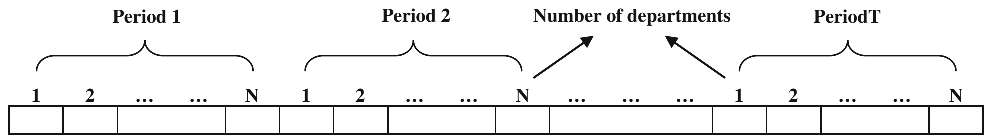

Fig. 1 Chromosome representation in the proposed algorithm

and through three old decades, genetic algorithms are introduced as effective optimization and search methods.

Genetic algorithms operate with populations, which are named chromosomes and encoded solutions of the problem. Each chromosome is made of fundamental cells. In each chromosome, a fitness value determines success rate. Usually, the initial population generates randomly and in order to generate new population, the evolution process considers to fitness performs by selection, crossover, and mutation operators.

The proposed GA algorithm uses FBS to represent the dynamic facility layout with the unequal area department. Conceptually, FBS divides the facility into vertical or horizontal bays. The bay width is flexible, depending on the departments that it contained. In addition, the number of bays and the number of departments in each bay are also flexible. The proposed algorithm tries to find the optimum value for the number of bays, the number of departments contained in each bay, and the department's placement order which could minimize the objective function value.

4.1 Encoding of a solution

In the genetic code which is used in this paper, each chromosome is formed by N×T genes, which is shown in Fig. 1. In this scheme, each gene is a random number between 1 and $B_t + 1$ which integer part represents the number of bay and decimal part represents department sequence in each bay (smaller numbers have priority). In this paper, the numbering of the bays is from left to right (from x=0) and sequence position of the department is from bottom to top (from y=0)

Figure 2 shows a layout plan for a DFLP with six departments and three periods in the planning horizon. For instance, in Fig. 2, gene related to the sixth department in second period has 3.66 value. It means this department in second period will be arranged in the third bay and since in the comparison with other departments (second and fifth departments, respectively, with 3.01 and 3.96 values) in this bay has the second rank, in this layout, it gained the second priority.

4.2 Fitness function

Evaluation of solutions is based on material handling and rearrangement costs. Therefore, less cost will introduce better fitness. Equation (28) shows fitness function.

$$Cost_s = \sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{j\neq i}^{N} C_{tij}F_{tij}d_{tij} + \sum_{t=2}^{T}\sum_{i=1}^{N} A_{ti}r_{ti} + \sum_{t=2}^{T}\sum_{i=1}^{N} R_{ti}p_{ti} \tag{28}$$

In above equation, number of departments, F_{ij} is the material flow between departments i and j, C_{ij} consist in transport cost of each material unit in each distance unit between departments i, j, and d_{ij} is rectangular distance between the center of departments i, j; in addition, is F_{ij} rearrangement fixed cost and A_{ij} is rearrangement variable cost. It should be remembered that, during solution manufacture, some of solutions may have departments with impractical shapes. It means departments are very long or very narrow. In problems with flexible bay structure, with the aim of preventing from producing such solutions, max aspect ratio criterion is used. If α_i, the aspect ratio is obtained from department i from a solution (layout) this solution is feasible, if and only if $\alpha_i \leq \alpha_i^{\max}$, for each department i. If the problem data instead of $\alpha_i^{\max}$, minimum allowed side length ($l_i^{\min}$) for a department i is given, then $\alpha_i^{\max}$ is calculated as $\alpha_i^{\max} = a_i \times (l_i^{\min})^{-2}$ where a_i is the area of department i.

Proposed genetic algorithm, by considering the penalty for infeasible solutions, prevents from choosing them. Penalty function is as following:

$$\text{penalty}_s = \left(\text{Cost}_{\text{feas}}^{\min} - \text{Cost}_{\text{all}}^{\min}\right) \times \left(\sqrt{n_s\left(1 + \sum_{i=1}^{N} \max\{0, \alpha_i - \alpha_i^{\max}\}\right)}\right)^k \tag{29}$$

In above equation, $\text{Cost}_{\text{feas}}^{\min}$ is the least material handling cost related to feasible solutions, and $\text{Cost}_{\text{all}}^{\min}$ is the least material

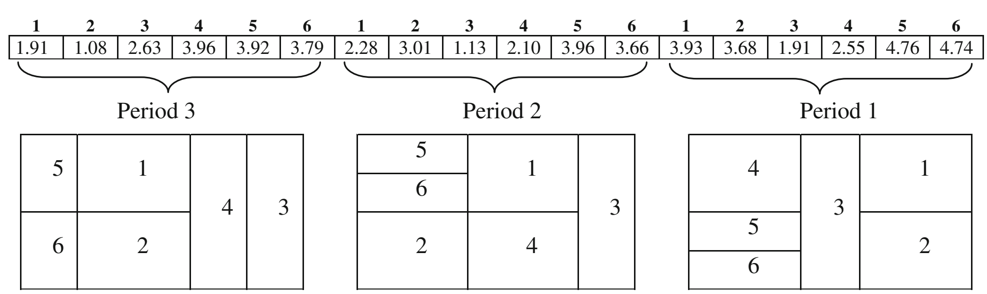

Fig. 2 Layout plan for generated from the chromosome representation

Fig. 3 Crossover operator in the proposed algorithm

4	3	2	1	4	3	2	1	
1.78	2.6	2.49	3.72	1.7	2.67	1.78	3.38	**Parent 1**
1.61	3.23	1.55	3.93	2.23	3.25	3.42	2.78	**Parent 2**
0.26	0.11	0.27	0.74	0.03	0.11	0.55	0.36	**Random chromosome**
1.65	3.16	1.8	3.77	2.21	3.18	2.51	2.99	**Child 1**
1.73	2.66	2.23	3.87	1.7	2.73	2.68	3.16	**Child 2**

handling cost related to feasible or infeasible solutions, which is found during the search so far. In addition, k is the severity parameter and n_S is equal to number of departments, which contravene constraint of shape. In many researches, n_S or $\sum_{i=1}^{N}\max\{0,\alpha_i-\alpha_i^{\max}\}$ as penalty function is used. In this research, their geometrical average as coefficient of penalty function has been used. This work causes more distinctiveness between different conditions of infeasible layouts. Cost function by considering the penalty for infeasible layouts is as following:

$$\mathrm{Cost}_s^p=\mathrm{cost}_s+\left(\mathrm{cost}_{\mathrm{feas}}^{\min}-\mathrm{cost}_{\mathrm{all}}^{\min}\right)\times\left(\sqrt{n_s\left(1+\sum_{i=1}^{N}\max\{0,\alpha_i-\alpha_i^{\max}\}\right)}\right)^k \tag{30}$$

4.3 Selection method

In this paper, roulette wheel selection method has been used. The probability of selecting the chromosome with higher fitness is more. Selection probability for each chromosome is computed from Eq. (31) based on fitness of that chromosome.

$$p_s=\frac{e^{-\beta\frac{\mathrm{cost}_s^p}{\mathrm{cost}_{\max}^p}}}{\sum_{i=1}^{n}e^{-\beta\frac{\mathrm{cost}_i^p}{\mathrm{cost}_{\max}^p}}} \tag{31}$$

While Cost_s^p is chromosome cost, and $\mathrm{Cost}_{\max}^p$is the most resulted cost, in above equation. Also, β is the severity parameter and is adjusted in order to cause half of chromosomes have probability of 80 %.

4.4 Crossover operator

Crossover is the process of taking two parent solutions and producing a child from them. After the selection (reproduction) process, the population is enriched with better individuals. Reproduction makes clones of good strings but does not create new ones. Crossover operator is applied to the mating pool with the hope that it creates a better offspring. The basic parameter in crossover technique is the crossover probability (p_c). Crossover probability is a parameter to describe how often crossover will be performed [39].

Crossover operator, used in this paper, is a continuous uniform crossover. In continuous uniform crossover, at first, two chromosomes are chosen, then a random chromosome with uniform distribution between 0 and 1 is produced, in same length, with existent chromosomes and by using Eqs. (32) and (33), children are created.

$$y_{1i}=\lambda_i x_{1i}+(1-\lambda_i)x_{2i}\forall i=1,2,\ldots,N \tag{32}$$

$$y_{2i}=\lambda_i x_{2i}+(1-\lambda_i)x_{1i}\forall i=1,2,\ldots,N \tag{33}$$

In above equations x_{1i} and x_{2i}, respectively, first and second parents' genes, y_{1i} and y_{2i}, respectively, are first and second genes and children. In addition, λ_is are random chromosome genes. The manner of crossover operation performance in Fig. 3 for a problem with four departments and two periods are illustrated.

4.5 Mutation operator

After crossover, the strings are subjected to mutation. Mutation introduces new genetic structures in the population by randomly

Table 1 Summary of test problems

Problems	Number of departments	Plant floor dimensions ($W\times H$)	Shape constraint	Data reference
VC10[a]	10	51×25	$l^{\min}=5$	Van Camp et al. [40]
VC10R$_s$	10	51×25	$l^{\min}=5$	Van Camp et al. [40]
VC10R$_a$	10	51×25	$\alpha^{\max}=5$	Gau and Meller [41]
BA12	12	10×6	$l^{\min}=1$	Bazaraa [42]
BA14	14	9×7	$l^{\min}=1$	Bazaraa [42]
NUG12	12	4×3	$\alpha^{\max}=4$	Nugent et al. [43]
NUG15	15	3×5	$\alpha^{\max}=4$	Nugent et al. [43]
AB20	20	30×20	$\alpha^{\max}$=varies	Armour and Buffa, [44]

[a] Euclidean distance

modifying some of its building blocks. Mutation helps escape from the local minima's trap and maintains diversity in the population. The important parameter in the mutation technique is the mutation probability (p_m). The mutation probability decides how often parts of chromosome will be mutated [39].

In this paper, three different mutation operator are used.

- A gene is selected randomly then is replaced with a random number between 1 and B+1 which is produced as following:

$$x_i^{'} = \begin{cases} x_i + ((B+1) - x_i)\tanh(kz) & \tanh(kz) \geq 0 \\ x_i + (x_i - 1)\tanh(kz) & \tanh(kz) < 0 \end{cases} \quad (34)$$

  In the above equation, x_i is value of chosen random gene, $x_i^{'}$ is replaced value, z is a standard normal random number, and k is its coefficient. The usage of the above method causes mutations in the neighborhood of previous gene, with more probabilities, to be accomplished and is prevented from extreme changes.
- Three genes in a period are chosen randomly, and then between binary and triple exchanges of genes, the exchange that causes the least cost is accomplished.
- A period of a chromosome is randomly chosen, and then 2-opt procedure is implemented. The 2-opt procedure considers all binary exchanges between each department position with other department positions in the layout. The one among these proposed exchanges that would result in a layout with the biggest decrease in the objective function is implemented.

4.6 Replacement

In this paper, the new population is selected among parents and children because the presence of the same chromosome among the population may cause convergence prematurely. Only chromosomes are selected among parents and children who previously were not selected for the presence in the new population.

4.7 Termination criterion

In this paper, the genetic process will end if there is no change to the population's best fitness for a specified number of generations.

5 Numerical experiments and computational results

In this section, efficiency of proposed GA algorithm will be evaluated by solving several examples. Therefore, examples are presented in static and dynamic areas. If in the DFLP, the number of periods is assumed to be one, DFLP will be transformed to SFLP. As SFLP, based on FBS, was studied

Table 3 The best solutions found for problem AB20

α^{max}	Solution
1,000	1,18,5,20,8,7,6,2,4,19,3,10,14,9,15,12,17,13,16,11
50	1|18|5|20|8|7|6|2|4|19|3|10|14|9|15|12|17|13|16|11
25	1|11|16|17|12|13|15|10|14|3|19|4|2|5,9,8,7,6|20|18
15	11|16|17|12|15|20,8,7,2,4,19,9,10,14,3,13|5,6,1|18
10	11|16|17|12|15,13,14,10,9,19,3,1|5,20,8,7,2,4,6,18
7	11|16|17|13,12|15,14,10,9,3,1|5,19|20,8,7,6,2,4,18
5	11,16|15,17|13,14,10,9,12|3,19|20,8,7,2,4,6|1,5,18
4	11,16|15,17|13,14,10,9,12|3,19|20,8,7,2,4,6|1,5,18
3	11,16|15,13,17|14,10,9,12|3,19,5|1,2,4,7,8,6|18,20
2	16,17|11,15,12|13,14,9,10|1,3,19|5,8,7,2,4|20,6,18
1.75	16,17|11,15,12|13,14,9,10|1,3,19|5,8,7,2,4|20,6,18
1.70667	16,17|11,15,12|13,14,9,10|1,3,19|5,8,7,2,4|20,6,18

Table 2 Results for AB20 with varying α^{max} values

α^{max}	Tate and Smith [15]	Enea et al. [17]	Konak et al. [34]	Kulturel-Konak and Konak [37]	Wong and Komarudin [36]	Best proposed GA	Average solution of proposed GA	No. rep. with best	IMP[a] (%)
1,000	1,638.5	1,638.5	–	1,638.5	–	1,587.91	1,587.91	5	3.09
50	3,009.5	3,009.5	–	2,706.5	–	2,381.86	2,381.86	5	11.99
25	3,535.1	3,535.1	–	3,526.5	–	3,391.95	3,391.95	5	3.82
15	4,296.1	4,140.5	–	4,119.8	–	4,043.91	4,043.91	5	1.84
10	4,633.3	4,440.7	–	4,440.7	–	4,364.74	4,396.23	4	1.71
7	5,255	4,793.5	–	4,793.5	–	4,717.53	4,829.52	2	1.58
5	5,524.7	5,397.6	–	5,297.6	–	5,183.52	5,192.13	4	2.15
4	5,743.1	5,370.9	–	5,360.8	–	5,183.52	5,206.71	3	3.31
3	5,832.6	5,594.3	–	5,594.3	–	5,369.3	5,386.08	3	4.02
2	6,171.1	6,023.2	–	5,845.3	–	5,677.83	5,723.92	2	2.87
1.75	7,205.4	6,453.1	6,890.82	5,845.3	5,677.83	5,677.83	5,742.37	2	0
1.70667	6,662.9	6,029.3	–	5,845.3	–	5,677.83	5,863.46	1	2.87

[a] Imp (%), percent improvement from the previously reported best solution

Table 4 Summarizes the results for the other test problems

Problems	Konak et al. [34]	Kulturel-Konak and Konak [37]	Wong and Komarudin [36]	Best proposed GA	Average solution of proposed GA	No rep. with best	IMP (%)
VC10	–	20,320.52	–	20,320.52	20,320.52	5	0
VC10Rs	22,899.65	22,899.65	22,899.65	22,899.65	22,899.65	5	0
VC10Ra	21,463.07	21,463.07	21,463.07	21,463.07	21,463.07	5	0
BA12	8,801.33	8,801.33	8,786	8,786	8,892.52	3	0
BA14	5,004.55	5,004.55	5,004.55	5,004.55	5,037.47	4	0
Nug12	265.5	262.003	262.003	262.003	262.003	5	0
Nug15	526.75	524.75	536.75	524.75	524.75	5	0

by other researches before, so common examples in literature are used for evaluating proposed algorithms. Furthermore, the results of the proposed approach will be compared with previous researches. Considering that this research is the first study in DFLP based on FBS, two well-known samples of DFLP will be investigated, and then some random examples will be created in order to produce better evaluations. These examples are solved by CPLEX 12 solver of GAMS 23.3 software and proposed GA. The proposed genetic algorithm was coded by MATLAB 7.9 software. Finally, these two methods are compared with each other. All the problems were tested by a PC with core 2 duo processor (2.2 GHz), 4 GB memory, and a Windows 7 operating system.

5.1 Numerical experiments for SFLP

Test problems used in this article and summary of their properties such as the size, shape constraint, and original data source are given in Table 1. In the first and fifth columns of Table 1, respectively, the name of test problems and source data is given. In the second column of this table, the number of departments, in the third column, the length and width of the layout, and limitation in the fourth column is expressed.

In these examples, performance of proposed GA is compared with the others like GA of Tate and Smith [15], hybrid fuzzy model and genetic search of Enea et al. [17], MIP approach of Konak et al. [34], ASA of Wong and Komarudin [36], and ACO of Kulturel-Konak and Konak [37]. To be consistent with these papers, only vertical bays are used.

Table 5 The best solutions found for the other test problems

Solution	Problems
3, 5 | 4, 8 | 7, 10 | 9 | 6, 2 | 1	VC10
1 | 7, 6 | 4, 2 | 8, 10, 9 | 5, 3	VC10Rs
1 | 6, 2 | 7, 4, 9 | 10, 8, 5, 3	VC10Ra
7, 6 | 1, 2, 3 | 12, 8, 11 | 9, 5, 10 | 4	BA12
10, 5, 11 | 1 | 3 | 13, 12, 6, 9 | 2 | 4 | 14, 8, 7	BA14
4, 8, 7,11, 9, 12 | 5, 1, 6, 10, 2, 3	Nug12
12, 5, 6, 15, 10 | 11, 9, 8, 7, 13, 14, 2, 3, 4, 1	Nug15

Problem AB20 is still considered as a fairly large problem which cannot be optimized in a reasonable period of time. Tate and Smith [15] studied AB20 based on FBS and different maximum aspect ratios between 1.70667 and 1000. Then, Enea et al. [17] solved the same problems using a hybrid fuzzy model and genetic, and improved some of the GA result of Tate and Smith. In 2010, Wong and Komarudin [36], and Kulturel-Konak and Konak [37] improved previous results using ASA and ACO, respectively.

Because the aforementioned approaches are based on FBS, the solution of AB20 problem provides a good benchmark to study the performance of the proposed GA over different maximum aspect ratios. In Table 2, the best and average results of proposed GA, as well as the number of replications in which the best solution was observed for five replications are shown. The best solutions as well as the best solutions were obtained by previous researches. In Table 2, the best solution in all researches is set as bold. In the last column of the table, percent improvement from the previously reported best solution is given. Needless to say that the propose algorithm shows potential; and in comparison with former approaches in 11 out of 12 cases, the maximum aspect ratio has better performance. These 11 new results are the best known results for AB20 problem with maximum aspect ratio.

Table 3 shows the details of the best proposed GA solutions found for AB20 with various maximum aspect ratios. In this table, the proposed GA solutions are coded such that bays are separated by bar symbols (|) and the order of the departments within the bays is given from bottom to top. As displayed using the AB20 problem instances, the proposed

Table 6 Parameter settings for the genetic algorithm

Population size	Termination criterion	p_c	p_m
50	250	0.8	0.2

Fig. 4 Results for comparison 2 with rearrangement costs

Period 1

7	3	8
5	2	9
6	1	4

Period 2

7	1	8
2	3	9
4	5	6

Period 3

7	4	3
2	5	9
8	1	6

Period 4

9	1	8
2	3	4
7	5	6

Period 5

9	6	4
2	3	5
7	8	1

GA can impressively search solutions with very different structures and it can find feasible solutions with severe maximum allowed aspect ratio as low as 1.70667.

In order to compare our proposed genetic algorithm results, Table 4 is presented. Table 4 summarizes the results for the other test problems that have been previously studied in literature using FBS. Most of these problems are optimality solved by MIP approach [34]. Table 4 shows that proposed genetic algorithm can find the optimal FBS solutions for these problems. In Table 4, the best-known FBS solution for each problem is set as bold. Table 5 shows the details of the best proposed GA solutions found for these problems. All the genetic algorithm parameter settings were obtained experimentally and are given in Table 6.

5.2 Numerical experiments for the discrete DFLP

According to literature review, most of the DFLP in discrete layout were formulated and solved. In DFLP with using FBS, when area and aspect ratio for all departments is equal to one, then the layout will be the same as discrete layout problem. Thus, discrete layout problem is the specific status of FBS. So, the results of algorithm are first compared with two well-known sample problems from the literature. The first comparison is made with Rosenblatt's problem [21] which has six departments in five periods and 2×3 plant floor. The optimum solution for this problem is 71,178 and several other researchers also obtained it. Presented algorithm obtains the optimal solution too.

The second comparison is made with the problem given by Conway and Venkataramanan [10] which has nine departments in five periods and 3×3 plant floor. The optimal solution with no rearrangement costs is 592,029 in which the proposed algorithm also obtains it. The optimum solution for this problem with rearrangement costs is unknown. The best solution found by the proposed algorithm is equal to 606,762, which is better than the known solutions (the best solution found by the genetic algorithm of Conway and Venkataramanan [10] was 608,904 and the best solution found by the SA algorithm of Baykasoglu and Gindy [24] was 607,421). Obtained plan layout is illustrated in Fig. 4.

5.3 Numerical experiments for the DFLP based on FBS

As it was stated, discrete problems are a particular type of flexible bay structure problems and cannot mention whole flexible bay structure problems assumptions. Also, since the same problem has not been solved for dynamic layout problems so far, to evaluate proposed algorithm more comprehensively, problems with random data and various sizes were generated (material flow matrix, facility dimensions, and rearrangement costs were generated randomly) at first, then algorithm results was compared with GAMS software output. The first comparison is made for a problem with four departments and three periods (FBS-DFLP-1), the second one for five departments and two periods (FBS-DFLP-2), the third for eight departments and six periods (FBS-DFLP-3), and finally the fourth for 12 departments and four periods (FBS-DFLP-4). Data of the aforementioned problems and the best layout plan obtained by the genetic algorithm are completely addressed in Appendix A to D. Each test problem was solved five times with using the genetic algorithm. Table 7 summarizes the results obtained by the GA and GAMS software. In this table, the best and worst solutions and average of answers for five times using the proposed algorithm is given and compared with GAMS software output. It is worth noting, in FBS-DFLP-1 and FBS-DFLP-2, that even the worst solutions of the proposed algorithm are consistent with the optimum solutions of test problems.

The results show that the genetic algorithm for small problems (FBS-DFLP-1 and FBS-DFLP-2) is faster than GAMS software. Also, in rather large problems (FBS-DFLP-3 and FBS-DFLP-4), GAMS software cannot obtain the optimal

Table 7 Summarize the results obtained by the GA and GAMS

Problems	Genetic algorithm				GAMS	
	Worst solution	Average solution	Best solution	Average run time (second)	Best solution	Run time (second)
FBS-DFLP-1	681.3668	681.3668	681.3668	7.25	681.3668	2,489.62
FBS-DFLP-2	567.8750	567.8750	567.8750	16.19	567.8750	1,302.52
FBS-DFLP-3	26,275.8896	25,866.6288	25,054.7145	3,909.91	27,612.2302	8,6744.46
FBS-DFLP-4	45,952.0471	45,545.1780	45,201.9503	3,016.44	52,332.8059	86,744.46

solution in a reasonable time (24 h); the genetic algorithm results in better solution in a short time. The above table shows the best solution of GAMS software after 24 h running for problems FBS-DFLP-3 and FBS-DFLP-4.

6 Conclusion

This paper presented a new type of dynamic facility layout based on flexible bay structure. Also, a genetic algorithm was proposed to solve the problem. Flexible bay structure divides the plant floor to vertical or horizontal bays. Generated layout, based on FBS, is a continuous one in which departments should be assigned to parallel bays with various widths. The proposed algorithm was tested on some numerical experiment and due to obtained results (Tables 4 and 6), it is efficient. This efficiency is considerable in different aspects which are: (1) solving discrete DFLP and the SFLP based on FBS, as good as previous algorithms and (2) solutions' quality and computational time are better than GAMS software. Using other metaheuristic algorithms (like ACO and TS) and studying this problem in multi-objective mode suggested for the future researches.

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Appendix A Dataset and optimum layout plan obtained for FBS-DFLP-1

Width of the plant floor along the x-axis is 11 and length of the plant floor along the y-axis is 6.

Number of periods is 3 (i.e., T=3)

Number of departments is 4 (i.e., N=4)

Expected ratio is 4 for all departments in all periods.

Maximum number of the parallel bays is 3 in all period.

Rearrangement fixed cost is 8 for all departments in all periods.

Rearrangement variable cost is 1 for all departments in all periods.

Table 8 Flow between departments and department area for the FBS-DFLP-1

Period 1					Period 2					Period 3						Area
	1	2	3	4		1	2	3	4		1	2	3	4		For all period
1	0	6	1	2	1	0	5	2	3	1	0	1	7	6	1	18
2	0	0	4	7	2	7	0	1	7	2	0	0	6	4	2	14
3	0	3	0	4	3	1	0	0	5	3	7	7	0	3	3	21
4	1	5	6	0	4	6	6	4	0	4	3	3	2	0	4	13

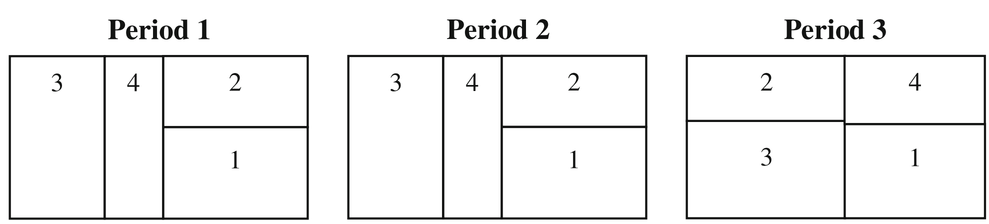

Fig. 5 Optimum layout plan for the FBS-DFLP-1

Appendix B Dataset and optimum layout plan obtained for FBS-DFLP-2

Width of the plant floor along the x-axis is 15 and length of the plant floor along the y-axis is 8.

Number of periods is 2 (i.e., T=2)

Number of departments is 5 (i.e., N=5)

Expected ratio is 4 for all departments in all periods.

Maximum number of the parallel bays is 3 in all period.

Rearrangement fixed cost is 12 for all departments in all periods.

Rearrangement variable cost is 1 for all departments in all periods.

Table 9 Flow between departments and department area for the FBS-DFLP-2

Period 1						Period 2							Area
	1	2	3	4	5		1	2	3	4	5		For all period
1	0	2	4	2	5	1	0	3	4	3	4	1	18
2	0	0	5	4	1	2	4	0	0	0	1	2	26
3	2	4	0	1	3	3	2	1	0	2	2	3	30
4	4	1	2	0	2	4	4	1	5	0	0	4	26
5	1	1	1	0	0	5	4	4	2	0	0	5	20

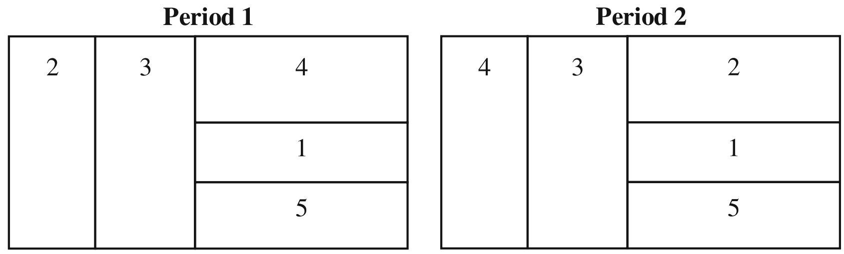

Fig. 6 Optimum layout plan for the FBS-DFLP-2

Appendix C Dataset and best layout plan obtained for FBS-DFLP-3

Width of the plant floor along the x-axis is 15 and length of the plant floor along the y-axis is 10.

Number of periods is 6 (i.e., T=6)
Number of departments is 8 (i.e., N=8)
Maximum number of the parallel bays is 3 in all period.

Table 10 Flow between departments for the FBS-DFLP-3

Period 1									Period 2								
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
1	0	4	19	20	19	18	12	18	1	0	20	2	12	20	14	20	18
2	15	0	11	1	14	14	9	18	2	9	0	14	13	13	9	4	19
3	9	15	0	1	13	12	3	4	3	15	16	0	10	4	5	5	15
4	12	14	9	0	0	6	18	9	4	14	9	4	0	15	2	5	13
5	8	13	17	19	0	16	14	1	5	13	20	16	18	0	13	6	13
6	4	16	12	11	0	0	8	1	6	1	10	5	19	1	0	14	19
7	14	12	6	2	2	9	0	20	7	1	0	9	3	20	13	0	14
8	19	15	11	2	11	15	6	0	8	5	4	3	20	4	20	0	0
Period 3									Period 4								
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
1	0	3	16	17	5	14	13	6	1	0	13	16	2	18	4	15	3
2	9	0	11	18	16	18	2	15	2	10	0	3	7	16	14	13	14
3	8	12	0	3	14	7	10	12	3	16	17	0	10	1	8	7	8
4	13	14	16	0	5	4	17	6	4	19	8	9	0	3	11	6	10
5	10	13	7	18	0	3	10	18	5	16	2	14	16	0	1	18	5
6	11	5	7	8	16	0	11	2	6	6	3	10	1	8	0	19	4
7	7	11	12	1	3	11	0	15	7	2	15	9	15	0	0	0	16
8	12	10	17	17	19	5	16	0	8	5	6	2	12	19	5	20	0
Period 5									Period 6								
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
1	0	3	15	0	17	5	7	9	1	0	7	6	16	0	4	20	8
2	15	0	8	7	4	4	7	1	2	1	0	4	12	5	16	8	17
3	15	15	0	20	1	11	11	7	3	14	8	0	1	11	13	18	15
4	0	4	5	0	14	11	8	13	4	8	9	15	0	5	8	6	16
5	13	13	19	5	0	5	11	3	5	7	17	7	11	0	5	2	4
6	5	9	10	15	8	0	17	5	6	20	10	6	3	11	0	16	16
7	4	12	6	15	8	16	0	14	7	13	13	10	17	5	18	0	18
8	12	13	4	4	17	18	19	0	8	6	8	7	3	6	4	9	0

Table 11 Department area, expected ratio, and rearrangement costs for the FBS-DFLP-3

	1	2	3	4	5	6	7	8
Area	23	16	33	13	10	19	10	26
Expected ratio	5	5	7	5	4	5	4	6
Rearrangement fixed cost	45	53	39	47	50	58	60	36
Rearrangement variable cost	2	2	3	2	1	2	1	3

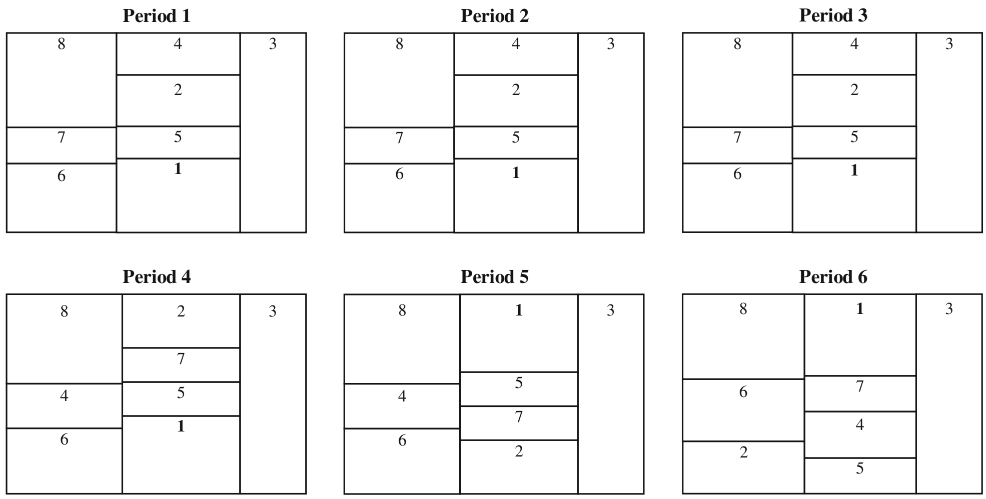

Fig. 7 Best layout plan for the FBS-DFLP-3

Appendix D Dataset and best layout plan obtained for FBS-DFLP-4

Width of the plant floor along the *x*-axis is 20 and length of the plant floor along the *y*-axis is 10.

Number of periods is 4 (i.e., $T=4$)

Number of departments is 12 (i.e., $N=12$)

Maximum number of the parallel bays is 5 in all period.

Table 12 Flow between departments for the FBS-DFLP-4

Period 1

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	6	3	8	17	9	10	14	18	12	14	13
2	19	0	1	9	11	18	5	13	10	17	8	5
3	18	12	0	15	3	1	13	18	7	7	17	7
4	9	4	8	0	3	11	11	15	11	5	15	14
5	16	3	12	10	0	16	15	13	8	14	18	19
6	5	18	1	12	16	0	7	1	14	7	2	10
7	19	7	0	14	16	7	0	11	1	15	8	14
8	10	11	20	3	3	19	12	0	10	15	10	14
9	10	6	6	17	8	10	19	19	0	10	3	5
10	7	2	16	4	3	2	12	7	17	0	13	4
11	15	0	19	11	9	2	13	10	4	10	0	7
12	8	6	16	19	16	16	3	2	12	15	6	0

Period 2

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	12	1	9	15	13	1	9	7	20	10	9
2	14	0	6	3	2	4	3	10	4	17	1	5
3	2	7	0	12	17	10	10	10	15	18	12	8
4	6	0	12	0	10	5	12	4	4	12	7	11
5	9	12	0	3	0	19	14	16	14	17	18	3
6	19	10	3	14	4	0	14	17	13	14	3	14
7	20	4	12	3	7	15	0	11	16	11	3	6
8	0	20	0	18	9	5	14	0	15	2	13	5
9	4	1	14	2	19	18	9	13	0	2	2	4
10	15	13	20	15	18	17	8	2	13	0	17	11
11	14	6	16	3	8	0	9	7	20	7	0	10
12	5	11	17	12	2	18	13	5	4	0	1	0

Period 3

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	2	11	19	7	18	0	15	19	10	3	1
2	4	0	16	8	20	2	6	19	5	4	4	2
3	9	12	0	5	5	4	2	16	12	7	2	0
4	11	13	13	0	5	8	15	7	0	7	11	8
5	17	6	16	3	0	4	13	5	6	13	3	9
6	12	14	13	18	13	0	3	8	1	8	3	19
7	12	4	7	12	5	6	0	17	15	13	7	19
8	17	13	11	0	1	14	13	0	10	3	15	13
9	13	12	19	13	7	13	3	17	0	3	13	10
10	6	11	3	2	15	10	6	11	14	0	18	1
11	11	16	13	1	3	10	4	9	19	10	0	8
12	13	0	5	13	15	15	4	16	8	1	10	0

Period 4

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	4	0	1	19	14	17	2	18	12	7	14
2	20	0	3	3	19	10	7	9	17	2	7	15
3	2	9	0	8	11	13	1	8	19	8	7	13
4	18	11	19	0	20	2	3	15	14	0	13	13
5	12	15	20	5	0	1	15	2	17	8	1	7
6	11	1	18	13	13	0	14	4	9	3	13	1
7	11	20	1	10	1	20	0	8	5	2	13	14
8	7	8	15	19	18	20	15	0	12	19	2	11
9	17	15	7	8	18	12	7	3	0	14	4	7
10	15	16	13	19	10	19	10	17	12	0	11	5
11	13	7	1	9	5	10	17	3	17	15	0	8
12	1	12	15	14	18	14	1	10	15	8	19	0

Table 13 Department area and expected for the FBS-DFLP-4

Area													Expected ratio												
	1	2	3	4	5	6	7	8	9	10	11	12		1	2	3	4	5	6	7	8	9	10	11	12
1	15	20	10	22	20	11	22	16	14	10	30	10	1	5	6	4	6	6	4	6	5	5	4	7	4
2	15	20	12	22	20	11	20	16	14	10	30	10	2	5	6	5	6	6	4	6	5	5	4	7	4
3	15	16	12	28	20	11	20	14	14	10	30	10	3	5	5	5	7	6	4	6	4	5	4	7	4
4	15	16	12	28	20	11	20	14	14	10	30	10	4	5	5	5	7	6	4	6	4	5	4	7	4

Table 14 Rearrangement costs for the FBS-DFLP-4

Rearrangement fixed cost													Rearrangement variable cost												
	1	2	3	4	5	6	7	8	9	10	11	12		1	2	3	4	5	6	7	8	9	10	11	12
1–2	44	31	40	49	47	46	55	54	56	44	56	37	1–2	2	3	2	3	3	2	3	2	2	2	4	2
2–3	38	55	59	36	33	46	40	51	59	54	55	46	2–3	2	3	2	3	3	2	3	2	2	2	4	2
3–4	33	33	53	54	57	41	56	53	40	41	44	48	3–4	2	2	2	4	3	2	3	2	2	2	4	2

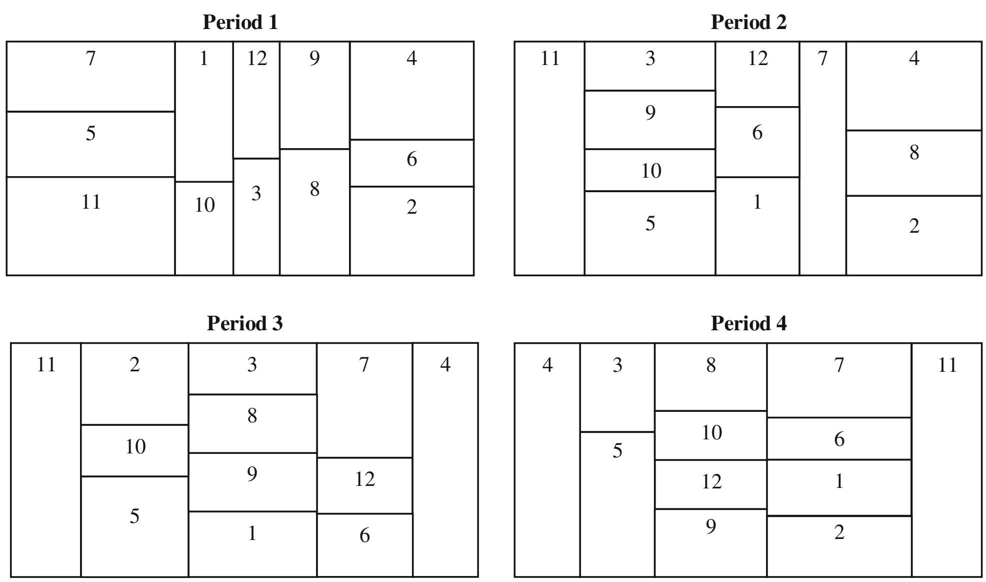

Fig. 8 Best layout plan for the FBS-DFLP-4

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