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ORIGINAL ARTICLE

An artificial bee colony algorithm for design and optimize the fixed area layout problems

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Abstract The placement of production equipments plays a major role in designing a layout in cellular manufacturing. The better placement increases the productivity. This article introduces a new algorithm to design and optimize a fixed area cellular layout problem by using an artificial bee colony (ABC) technique which is based on the intelligent foraging behavior of a honeybee. The objective of this article is to determine the physical arrangement of work centers by minimizing the total traveling distance of the product. Volume of the product and distance between the work centers are the important factors that affect layout design. Some relative importance factors like priority of products, hazardous moves, and back-tracking moves are considered in this article. Layout moment ratio helps to compare the different proposed layouts. The higher layout moment ratio is the more desirable layout. Also this article compares the results of ABC technique with genetic algorithm (GA) and simulated annealing (SA) algorithm based on the total moment value, layout moment ratio, number of iterations, computation time, and back-tracking movements. Finally, it concluded that ABC is a better technique to solve fixed area cellular layout problems than the mentioned algorithms with high dimensionality.

Keywords Cellular manufacturing · ABC algorithm · GA · SA algorithm · Relative importance factors

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1 Introduction

A facility layout is an arrangement of everything needed for production of goods or delivery of services. According to James, the layout involves the allocation of space and the arrangement of equipment in such a manner that overall operating costs are minimized. A facility is an entity that facilitates the performance of any job. It may be a machine tool, a work center, a manufacturing cell, a machine shop, a department, a warehouse, etc., according to Heragu [1]. The layout design generally depends on the product mix and the product volume. There are four types of organization referred to, namely product or line layout, process or functional layout, fixed position or location layout, and cellular or combined or group layout. In product layout, the machines or equipments are arranged in one line depending upon the sequence of operations required for the product as shown in Fig. 1. The material moves to another machine sequentially without any backtracking or deviation. It requires minimum material handling. It is used for mass production of standardized products. Smooth and continuous operations, less inventory and work in process, optimum usage of floor space are the merits of this layout.

Similar machines are arranged together at one place in process layout, as shown in Fig. 2. It is used for batch production. Also, it is preferred when the product is not standardized and the quantity produced is very small. It has higher degree of machine utilization and greater flexibility. It required lower investment. Work in process inventory and material handling costs are too high.

Figure 3 shows a fixed position layout; it involves the movement of manpower and machines to the product site which remains stationary. The movement of men and machines is advisable as the cost of moving them would be lesser. This type of layout is preferred where the size of the job is bulky and heavy. The advantages are small investment on

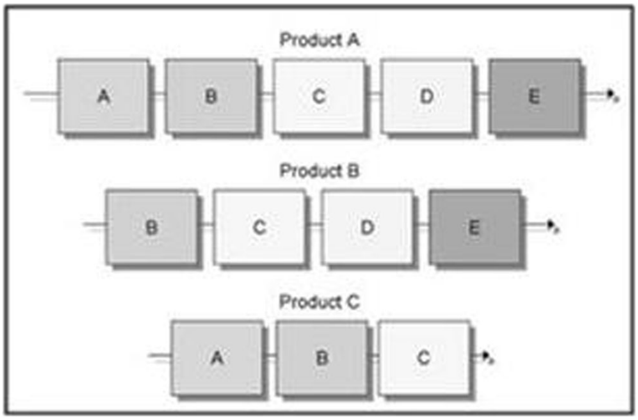

Fig. 1 Product layout

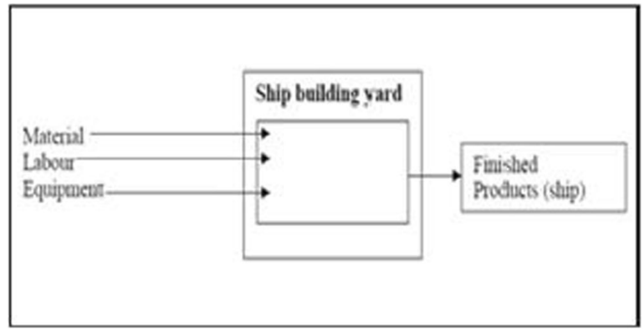

Fig. 3 Location layout

layout, high adjustment, and flexibility. Examples of such type of layout are locomotives, ships, boilers, generators, wagon building, aircraft manufacturing, etc.

The cellular layout (Fig. 4) is a combination of process and product type layouts and is based on the group technology (GT) principle. Therefore, it is also called as group or cellular layout.

According to Dilworth [2], the group technology principle suggests that parts, which are similar in design or manufacturing operations, are grouped into one family, called part-family. The cellular manufacturing is the grouping of the production equipment into machine cell where each machine cell specializes in the production of a particular part-family. GT is a manufacturing philosophy in which similar parts are identified and grouped together to take the advantage of their similarities in design and production. Similar parts are arranged into part families, where each part family possesses similar design and/or manufacturing attributes. A part family is a collection of parts that are similar either in geometric shape and size or in the processing steps required in their manufacturing. This layout is suitable for a manufacturing environment in which large variety of products are needed in small volumes (or batches). The cellular manufacturing eliminates over production and reduces waste by reducing defects. The other merits are better quality, high flexibility, more capacity, efficient production planning and control, easy plant maintenance, simplified tooling and setups, and better utilization of manufacturing resources and space. The advantages of reduced work piece handling yield lower setup times, fewer setups, less in-process inventory, and shorter lead times. After grouping the machines next setup is design of cellular layout. Cellular layout problems are families of design problems involving the placement or allocation of work centers, which have given fixed area. The work centers are placed optimally with shorter traveling distance of products [3]. Hassan [4] stated that the type of the machine layout is affected by a number of factors, namely, the number of machines, availability of floor space, part sequences, and the material handling systems. The type of material handling equipment plays an important role in the design and operation of a modern manufacturing facility. It determines the travel time and affects the throughput and the flexibility of the flexible manufacturing system (FMS).

There are two types of movements associated with the flow-line layout, which affects the flow of operations, namely, backtracking, and bypassing. Backtracking is the movement of a part from one machine to another that precedes it in the sequence of machines in flow-line arrangement. Backtracking occurs when the parts being processed have different sequence

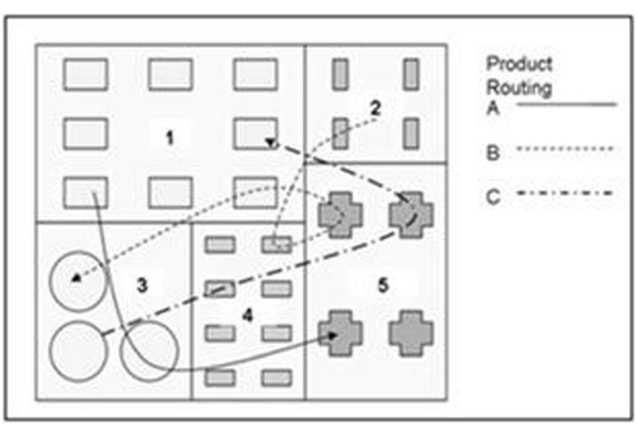

Fig. 2 Process layout

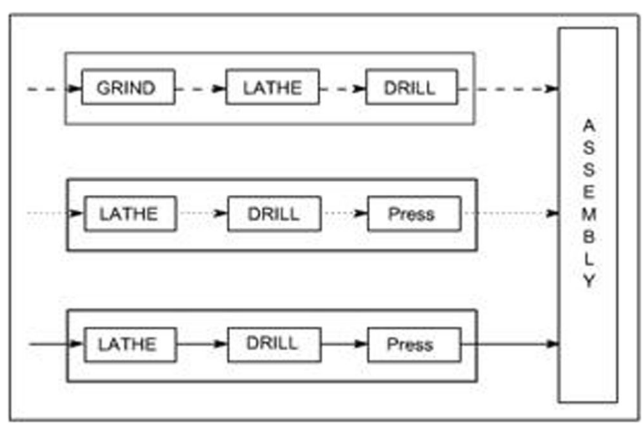

Fig. 4 Cellular layout

of operations in the flow-line type of arrangement. On the other hand, bypassing occurs when a part skips some machines while it is moving towards the end of a flow-line arrangement. Similar to backtracking, bypassing occurs due to the difference in the sequence of operations of the parts. Ideally, both of these movements should be minimized as much as possible since they affect the movement cost and productivity.

The overview of this article is structured as follows. Section 2 reviewed the related literatures. Section 3 describes the fixed area cellular layout problems. The objective function is formulated in section 4. Section 5 introduces the proposed ABC technique and adopted pseudo code shown in section 6. In seventh section, the control parameters of example 1 are given. The layout moment ratio is discussed in section 8. Results and comparison are explained in section 9. Section 10 gives guideline for the span of future research and section 11 concludes this article.

2 Literature survey

The diagrams and graphs are used to find the best layout in the conventional techniques. According to Apple [5], a detailed analysis should be done on the parts routing, parts volume, parts traveling distance, frequency of movement, and the cost of the movement. Assembly charts, from/to charts, multiproduct charts, and string diagrams are the older techniques used in layout problems [6]. A quadratic assignment problem (QAP) model was developed by Koopmans and Beckmann [7] to solve the multi-row layout problems with the objective of minimizing movements involved in materials handling. Afrazeh, Keivani, and Farahani [8] proposed a mixed integer programming (MIP) formulation for static and dynamic multi-floor facility layout problem. To reduce the mathematical calculations, King [9] proposed a rank order clustering (ROC) algorithm. Direct clustering algorithm (DCA) was developed for forming component families and machine groups for cellular manufacturing [10].

This is an effective and efficient approach which offers great flexibility in determining the optimum families and groups. Some of the graph approaches include the heuristic graph partitioning (HGP) approach applied to solve cell design problems by Askin and Chiu [11] and Ng [12, 13]. Venugopal and Narendran [14] presented an algorithm based on SA algorithm to solve the machine-component grouping problem for the design of cells in a manufacturing system. An enhanced SA approach augmented with dynamic programming algorithm is developed to solve machine cell problems [15]. Wang et al. [16] formulated a model for solving both inter-cell and intra-cell facility layout problems for cellular manufacturing systems to minimize the total material handling distance on the shop floor.

Xambre and Vilarinho [17] developed a mathematical programming model for the cell formation problem with multiple identical machines, which minimizes the intercellular flow. Liang and Chao [18] developed the efficient strategies of tabu search (TS) algorithm to improve the layout in the facility layout problem. Singh [19] proposed an improved tabu search (ITS)-based approach for solving facility layout problem which is formulated as QAP. GA is very well known, having several applications to general optimization and combinatorial optimization problems [20]. Suresh et al. [21] used a genetic approach to solve the facility layout problem, where the objective is to minimize the cost of interaction between various departments. Unlike the machine layout problem, the facility layout problem is more involved in finding the best layout for cells/departments and not finding the arrangement of machines. Gupta et al. [22] used a GA to find the part family as well as the layout between cells. Lee et al. [23] proposed an improved GA to derive solutions for multi-floor facility layout problems. Balamurugan et al. [24] used GA to solve a multi-objective machine layout problem with unequal area and fixed shape.

An ant colony optimization (ACO) scheme for the manufacturing cell design problem is proposed by Spiliopoulos and Sofianpoulou [25]. ACO achieved better efficiency and reliability with minimum structure and set of parameters. Ming and Ponnambalam [26] implemented a hybrid search algorithm using GA and particle swarm optimization (PSO) for the concurrent design of cellular manufacturing system. A divide and conquer (DC) algorithm used to minimize the number of inter-cell movements between machine cells by Chiang and Lee [27].

Satheeshkumar et al. [28] developed a two-phase layout design. In the first phase, an artificial immune system (AIS) algorithm was used for solving the unidirectional layout problem, and results showed that the AIS algorithm is efficient in solving layout problems and producing good-quality solutions. In the second phase, shortcuts are introduced in the flow path of the loop layout to enhance the performance of the system. The position of the shortcut in the loop which gives the minimum material handling cost was discovered. Satheeshkumar et al. [29] used PSO technique for solving the loop layout problem. The clearance between the machines is considered in the design and it helps in choosing the best layout. An ABC algorithm is used by Karaboga and Basturk [30] for optimizing multivariable functions, and it produced better results than the other algorithms like GA, PSO, and particle swarm inspired evolutionary algorithm (PS-EA). Also, they compared the performance of ABC algorithm with that of differential evolution (DE), PSO, and EA for multi-dimensional numeric problems and concluded that the performance of ABC algorithm is efficiently employed to solve engineering optimization problems [31].

Karaboga and Akay used ABC technique for data clustering on benchmark problems and compared ABC technique with PSO algorithm with other techniques. The results indicate that ABC algorithm is efficient for multivariate data clustering [32]. Soimart Ponpimon and Pongcharoen Pupong [33] developed an automated MLD programming tool that applies ABC algorithm and reports the influence of ABC's parameters configuration on its performance. The results indicated that the ABC performance can be improved a lot after optimum parameter setting. The ABC optimization is a population-based search algorithm which applies the concept of social interaction to problem solving. This biological phenomenon was applied by Ashita et al. [34] to the process of path planning problems for the vehicles. The result was found to excel in solution quality as well as in computation time. One of the main objectives in FMS is to minimize the total material flow. In layout design, the placement of machines plays a vital role in minimizing the material flow. Satheeshkumar et al. [35] proposed scatter search technique for solving single-row unequal area facility layout problem. This approach is tested and it gives a better result.

Asokan et al. [36] proposed PSO approach to solve unequal area facility layout problems with the objective to minimize material flow between facilities and aspect ratios of the facilities. The proposed algorithm performed well than the existing algorithms. A detailed analysis on layout problems was done by Saravanan and Arulkumar [37].

A novel hybrid algorithm based on scatter search and SA technique was proposed by Krishnan et al. [38] for solving NP problem. The results obtained by this hybrid algorithm demonstrated a high rate of success than the routine heuristics algorithms when tested on benchmark FMS layout problems. Abraham et al. [39] described a novel hybrid differential artificial bee colony algorithm (HDABCA), which combines differential evolution strategy with artificial bee colony algorithm. The proposed method result is very efficient than the result obtained by classical differential evolution algorithm and artificial bee colony algorithm.

Kong et al. [40] proposed a hybrid ABC (HABC) to improve the performance of artificial bee colony algorithm for global optimization. A novel search strategy is developed and applied on six benchmark functions with various dimensions. Numerical results demonstrate that the proposed algorithm outperforms the ABC in global optimization problems. In the article, Bacanin and Tuba [41] introduced modifications to the ABC algorithm for constrained optimization problems that improve the performance of the algorithm. Modification is based on genetic algorithm operators. This modified algorithm was tested on 13 benchmark problems. The results were compared with the results of ABC algorithm developed by Karaboga and Ozturk [42] and the proposed modified algorithm showed an improved performance. Mahdavi et al. [43] developed a heuristic algorithm based on flow matrix for solving cell formation and layout design problems using sequence data.

3 Problem descriptions

3.1 Required data for layout design

A benchmark problem (example 1, i.e., 3Px8M) has been taken from the literature [3] and two more similar problems (10Px10M, 20Px12M) have been taken. ABC optimization technique is used to solve the problems.

Machine-part matrix, parts sequence, area of the machines, and area of the layout are the primary required data. The primary data should be included the production data, production center data and total area of the layout. The production data for three problems are shown in Table 1. It consists of product name, product sequence, and loads/unit time of each product. While designing a layout, loads of the product plays an important role.

A fixed area layout is different from fixed position layout. In the fixed area layout the length of two rows should be same and breadth of the work center must be 20 ft. The length of the aisle is equal to the length of the row and breadth of the aisle should be 10 ft. Aisle should be placed between the two rows of machines. The placement of the work center-1 is always in first position. The placement of machines should not affect the layout area. The data to be used in benchmark problem are presented in the above table.

The sample layout is given in Fig. 5. For example, 1-2-3-6-7-8 indicates that the product *a* starts from work center 1 and reach work center-8 through passing the work centers 2, 3, 6, and 7. The total number of work centers, name of the work centers and the area of the work centers are the data in the production center data which are shown in Table 2. The area of the individual work centers and total area of the layout are given as square footages. The work centers are arranged in two columns. An aisle is placed in between the two columns. The length of the aisle is equal to the length of the layout. The breadth of the aisle is taken as 10 ft for this problem.

3.2 Implementation of relative importance factors

A relative importance factor will be defined as any factor other than volume of product or distance to be moved that is to be considered in determining a good plant layout from a material handling point of view. Importance factors will be used to determine adjustments which will be applied to either the distances to be moved or to the volume of material to be moved.

Table 1 Production data

Product	Sequence	Loads/unit time
Production data for example 1 (3P)		
a	1-2-3-6-7-8	40
b	1-2-6-5-4-8	100
c	1-3-4-5-8	25
Production data for example 2 (10P)		
a	1-2-6-7-8-10	40
b	1-2-6-5-4-10	60
c	1-3-4-5-6-10	100
d	1-2-3-6-7-9-10	50
e	1-2-6-8-4-10	90
f	1-3-5-4-7-10	65
g	1-5-3-6-7-10	45
h	1-8-6-4-10	80
i	1-4-5-9-10	75
j	1-8-3-7-9-10	120
Production data for example 3 (20P)		
a	1-2-6-7-8-10-12	40
b	1-2-6-5-4-11-12	100
c	1-3-4-5-6-12	25
d	1-2-3-6-7-9-12	50
e	1-2-6-5-4-8-11-12	90
f	1-3-5-4-7-10-12	30
g	1-5-3-6-7-8-12	45
h	1-8-6-5-4-10-12	60
i	1-4-5-9-11-12	75
j	1-8-3-6-7-9-12	40
k	1-6-8-5-4-7-12	55
l	1-4-5-10-11-12	35
m	1-2-5-6-4-7-12	65
n	1-9-10-7-8-12	95
o	1-8-6-7-11-5-12	150
p	1-4-6-10-8-12	20
q	1-8-11-10-7-9-12	35
r	1-9-6-5-4-10-12	45
s	1-2-3-4-5-6-11-12	50
t	1-2-6-8-10-11-12	40

Referring to example 1, it has been found that the product *b* is the most stable product in terms of sales. It is likely that the product *b* will be produced for a long period of time, perhaps after the products *a* and *c* have been discontinued. Therefore, it will assign more important to the movement of product *b* than the products *a* and *c*. It is decided that a move of product *b* should be considered 1.4 times as important as a move of products *a* and *c* (refer Table 3). Product *a* has some radioactive materials in it at machine centers 6, 7, and 8.

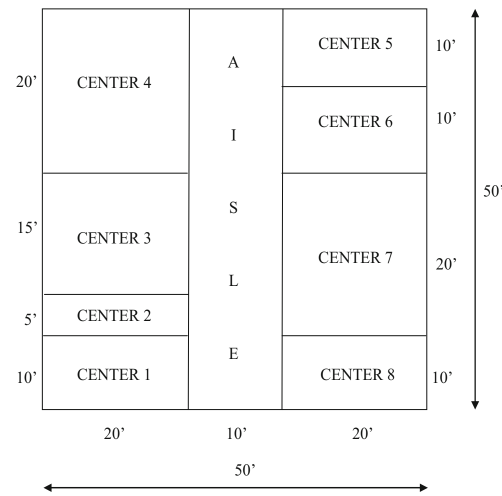

Fig. 5 Sample layout for example 1

The distance between the work centers, should be minimum. It is felt, therefore, that a high adjustment of 1.0 should be added to the base of 1.0 to make up the multiplier for those moves. In the example, normal flow has been defined as clockwise, both along aisles and across them. For this layout, the counter flow is undesirable.

The counter flow is called backtracking. The multiplier value is 1 for clockwise move; the multiplier value is 1.2 for counter clockwise move. A benchmark fixed area layout problem (example 1) with 8 machines and 3 parts has been taken. There are about 40,320 (i.e., 8!) different possible arrangements for 8 machines. Among these possible placements, 10 sequences are selected randomly. The machines (assume the position of machine 1 is fixed) may be placed anywhere and at any position within the cell. While determining the physical location of work centers, it is important to consider some relative importance factors; which affect the layout. The usual factors are volume of the product and distance. The others like priority of one product over others, hazardous moves, and back-tracking moves are too important to consider to the particular product.

The moment value is defined as product of distance value, adjusted load value, and multiplier. The distance value is the summation of the distance from the centroid of machine *i* to the horizontal center of the aisle, distance from the horizontal center of the aisle to the centroid of machine *j*, distance from the centroid of machine *i* to the centroid of machine *j*. In example 1, the distance value of move 1–2 for product *a* is 37.5 (i.e., 15+7.5+15), adjusted load value is 40 and the multiplier value is 1. The moment value is 1500 (i.e., 37.5×40×1). Likewise, the moment value is calculated for each move. Sum of the moment values of each move is called total moment value for the particular machine sequence. The total moment value is calculated for 10 sequences which are selected randomly. The 10 sequences are ranked in descending order based on their total moment value.

Table 2 Production center data

Number	Center	Area (sq. ft)
Production center data for example 1 (8M)		
1	Receiving	200
2	Band saw	300
3	Lathes	100
4	Grinders	400
5	Milling machines	200
6	Drill processes	200
7	Polishers	400
8	Packaging	200
Production center data for example 2 (10M)		
1	Receiving	200
2	Lathe	300
3	Drilling	100
4	Boring	200
5	Shaper	200
6	Planer	200
7	Milling	200
8	Grinding	100
9	Polishing	300
10	Packaging	200
Production center data for example 3 (12M)		
1	Receiving	200
2	Power saw	300
3	Lathe	100
4	Drilling	200
5	Tapping	100
6	Boring	200
7	Shaper	200
8	Planer	100
9	Milling	200
10	Grinding	200
11	Polishing	100
12	Packaging	300

Table 3 Weight importance factors

Factors	Move	Adjustment	Multiplier
Example 1			
Product priority	Product *b*, 1 to 2	0.4	1.4
	Product *b*, 2 to 6	0.4	1.4
	Product *b*, 6 to 5	0.4	1.4
	Product *b*, 5 to 4	0.4	1.4
	Product *b*, 4 to 8	0.4	1.4
Hazardous	Product *a*, 6 to 7	1.0	2.0
	Product *a*, 7 to 8	1.0	2.0
Directional	Clockwise	1.0	1.0
	Counterclockwise	1.0	1.2
Example 2			
Product priority	Product *j*, 1 to 8	0.4	1.4
	Product *j*, 8 to 3	0.4	1.4
	Product *j*, 3 to 7	0.4	1.4
	Product *j*, 7 to 9	0.4	1.4
	Product *j*, 9 to 10	0.4	1.4
Hazardous	Product *b*, 6 to 5	1.0	2.0
	Product *b*, 5 to 4	1.0	2.0
	Product *f*, 5 to 4	1.0	2.0
	Product *f*, 4 to 7	1.0	2.0
Directional	Clockwise	1.0	1.0
	Anticlockwise	1.0	1.2
Example 3			
Product priority	Product *o*, 1 to 8	0.4	1.4
	Product *o*, 8 to 6	0.4	1.4
	Product *o*, 6 to 7	0.4	1.4
	Product *o*, 7 to 11	0.4	1.4
	Product *o*, 11 to 5	0.4	1.4
	Product *o*, 5 to 12	0.4	1.4
Hazardous	Product *i*, 5 to 9	1.0	2.0
	Product *i*, 9 to 11	1.0	2.0
	Product *p*, 4 to 6	1.0	2.0
	Product *p*, 6 to 10	1.0	2.0
	Product *p*, 10 to 8	1.0	2.0
Directional	Clockwise	1.0	1.0
	Anticlockwise	1.0	1.2

Store the rank-1 sequence as the best which has the minimum total moment value. Next, search for another sequence with minimum value. Compare these values and the sequence that gives the minimum value is stored as the best value. Similarly, this process is continued up to the termination criteria.

4 Objective function

The machine layout problem is the placement of M non-identical machines to N locations in a specified manufacturing area. Due to the predefined sequences of machines for manufacturing multiple products, material handling distance is determined from material flow between machines corresponding to its sequence. The most common objective for designing machine layout is to minimize the total transportation distance of materials and placement/arrangement of machines in the manufacturing area. The objective function (1) is to determine the physical location of work centers and also to minimize the total moments within the cell. The

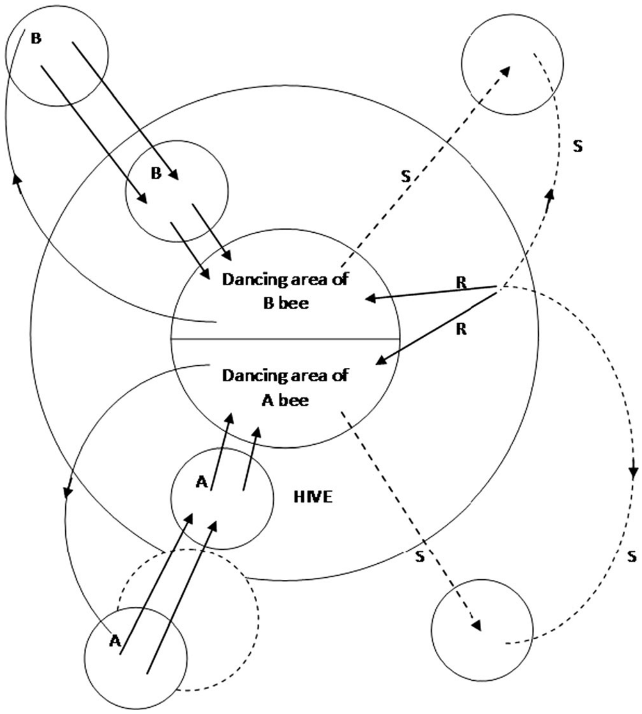

Fig. 6 The behavior of honeybee foraging for nectar

mathematical model and notations for the machine layout problem is as follows:

Minimize total moment

$$= \sum_{i=1}^{M}\sum_{j=1}^{M}\sum_{n=1}^{m}\left(d_i + d_{ij} + d_j\right)*(l_a)*(m_u) \qquad (1)$$

where

M denotes the number of machines;
m denotes the number of moves;
d_i denotes the distance from the centroid of machine i to the horizontal center of the aisle;
d_j denotes the distance from the horizontal center of the aisle to the centroid of machine j;
d_{ij} denotes the distance from the centroid of machine i to the centroid of machine j;

Placement	0	**1**	2	3	4	5	6	**7**
X_{ij}	1	**4**	5	7	8	3	2	6
X_{kj}	1	2	3	5	7	8	6	**4**
X_{kj}	1	**4**	3	5	7	8	6	**2**

Fig. 7 An improved sequence by swap operator

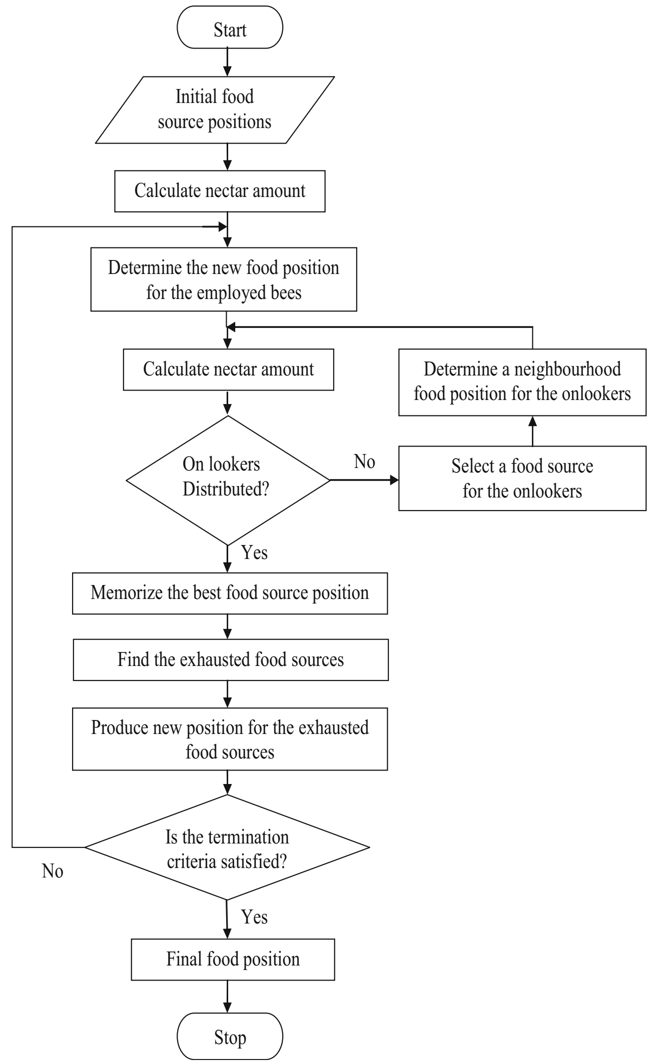

Fig. 8 Flowchart of ABC algorithm

Define number of bees (*F*), number of cycles (C_n) and unimproved cycle (*L*)
Initial the population of layouts (X_i); $i = 1, 2, 3, \ldots, F$.
Evaluate the population
Set Cycle = 1
Repeat

- Produce new layouts (V_i) as the employed bees and evaluate them.
- Apply greedy selection process for the employed bees.
- Calculate the probability value (P_i) for layouts.
- Produce new layouts (V_i) as the onlookers from X_i selected depending on P_i and evaluate them.
- Apply greedy selection process for the onlookers.
- Determine the abandoned layout for the scout according to *L*, if exits, replace it with one.
- Update the best achieved so far solution.
- Cycle = Cycle + 1

Until Cycle = C_n

Fig. 9 Pseudo code of ABC algorithm

l_a denotes the adjusted load value for the particular move; and

m_u denotes the multiplier value for the particular move.

The adjusted load value (l_a) is defined as the product of the volume of the material moved and the constant adjustment multiplier. This value is constant for all layouts. Each move has a separate value of load.

5 Proposed approach

Tereshko [44], Tereshko and Loengarov [45], and Tereshko and Lee [46] developed a model of foraging behavior of a honeybee colony. This model consists of food sources, employed bees, and unemployed bees. In this work, an intelligent foraging behavior of a honeybee is considered. ABC algorithm simulating the behavior of real honeybees is described for solving multidimensional and multimodal optimization problems.

The honeybee colony consists of three kinds of bees: employed bees, onlooker bees, and scout bees. The first half of the colony consists of the employed bees and the others are onlooker bees. Employed bees are responsible for exploiting the food sources and giving information to the onlooker bees in the hive about the quality of the food source site which they are exploiting. Karaboga and Basturk [31] explained the basic behavior characteristics of foragers with simple sketch. The behavior of honeybees foraging for nectar is shown in Fig. 6. The exchange of information among bees is the most vital task in information-collecting system. The dancing area is the most important part in the hive with respect to exchanging information about nectar quantity. The communication between bees takes place in the dancing area. Employed bees share their information with a probability proportional to the profitability of the food source, and the sharing of this information through dancing is longer in duration. An onlooker on the dance floor probably can watch numerous dances and decides to employ itself at the most profitable source. There is a greater probability of onlookers choosing more profitable sources since more information is circulated about the more profitable sources. Onlooker bees wait in the hive and decide a food source to exploit depending on the information shared by employed bees. Scouts randomly search and find a new food source.

Here, a possible solution is represented as the food source position and the nectar amount corresponds to the quality of the solution, i.e., fitness. Both the number of the employed bees and the onlooker bees is equal to the number of solutions in the population. Initially, it generates an initial population $P(C=0)$ of F solutions, where, F-size of employed bees or

Table 4 Layout analysis work sheet for example 1

Layout Analysis work sheet for 3Px8M

Move	Adjusted loads	TM (1 2 3 6 7 5 4 8)			GA (1 2 3 4 8 5 6 7)			SAA (1 6 5 7 8 4 3 2)			ABC (1 6 5 7 8 4 2 3)		
		Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment
1 to 2	180	1.0	42.5	7650.0	1.0	37.5	6750.0	1.0	32.5	5850.0	1.0	32.5	5850.0
2 to 3	40	1.0	40.0	1600.0	1.0	40.0	1600.0	1.2	40.0	1920.0	1.0	40.0	1600.0
3 to 6	40	1.0	37.5	1500.0	1.0	32.5	1300.0	1.2	32.5	1560.0	1.2	32.5	1560.0
6 to 7	80	1.0	40.0	3200.0	1.0	45.0	3600.0	1.0	55.0	4400.0	1.0	55.0	4400.0
7 to 8	80	1.0	70.0	5600.0	1.2	65.0	6240.0	1.0	35.0	2800.0	1.0	35.0	2800.0
2 to 6	140	1.0	47.5	6650.0	1.0	42.5	5950.0	1.2	42.5	7140.0	1.2	42.5	7140.0
6 to 5	140	1.0	30.0	4200.0	1.2	40.0	6720.0	1.0	40.0	5600.0	1.0	40.0	5600.0
5 to 4	140	1.0	45.0	6300.0	1.2	35.0	5880.0	1.0	35.0	4900.0	1.0	35.0	4900.0
4 to 8	140	1.0	45.0	6300.0	1.0	35.0	4900.0	1.2	45.0	7560.0	1.2	45.0	7560.0
1 to 3	25	1.0	52.5	1312.5	1.0	47.5	1187.5	1.0	37.5	0937.5	1.0	37.5	0937.5
3 to 4	25	1.0	37.5	0937.5	1.0	47.5	1187.5	1.2	47.5	1425.0	1.2	47.5	1425.0
4 to 5	25	1.2	54.0	1620.0	1.0	35.0	0875.0	1.2	35.0	1050.0	1.2	35.0	1050.0
5 to 8	25	1.0	60.0	1500.0	1.2	40.0	1200.0	1.0	50.0	1250.0	1.0	50.0	1250.0
Total moments		48,370.0			47,390.0			46,392.5			46,072.5		
Layout moment ratio		53,820/48,370=1.1			53,820/47,390=1.136			53,820/46,392.5=1.16			53,820/46,072.5=1.168		

Table 5 Layout analysis work sheet for example 2

Layout analysis work sheet for 10Px10M													
Move	Adjusted loads	TM (1835479 10 62)			GA (1639547 10 28)			SAA (163954 10 728)			ABC (183754 10 962)		
		Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment
1 to 2	240	1	42.5	10,200	1	37.5	9000	1	37.5	9000	1	32.5	7800
2 to 6	190	1	57.5	10,925	1.2	32.5	7410	1.2	32.5	7410	1.2	42.5	9690
6 to 7	135	1	40	5400	1	50	6750	1	40	5400	1.2	35	5670
7 to 8	40	1	37.5	1500	1	62.5	2500	1	52.5	2100	1.2	42.5	2040
8 to 10	40	1	52.5	2100	1.2	52.5	2520	1.2	62.5	3000	1	62.5	2500
6 to 5	120	1.2	30	4320	1	60	7200	1	60	7200	1.2	45	6480
5 to 4	250	1.2	40	12,000	1	30	7500	1	30	7500	1	40	10,000
4 to 10	230	1	60	13,800	1	50	11,500	1	40	9200	1	30	6900
1 to 3	165	1	52.5	8662.5	1	47.5	7837.5	1	47.5	7837.5	1	42.5	7012.5
3 to 4	100	1	37.5	3750	1	52.5	5250	1	52.5	5250	1	57.5	5750
4 to 5	175	1	40	7000	1.2	30	6300	1.2	30	6300	1.2	40	8400
5 to 6	100	1	30	3000	1.2	60	7200	1.2	60	7200	1	45	4500
6 to 10	100	1	70	7000	1	40	4000	1	50	5000	1.2	55	6600
2 to 3	50	1	40	2000	1.2	70	4200	1.2	70	4200	1.2	40	2400
3 to 6	95	1	47.5	4512.5	1.2	37.5	4275	1.2	37.5	4275	1	32.5	3087.5
7 to 9	218	1	47.5	10,355	1.2	32.5	8502	1.2	37.5	9810	1	37.5	8175
9 to 10	293	1	42.5	12,452.5	1	37.5	10,987.5	1	32.5	9522.5	1.2	42.5	14,943
6 to 8	90	1	47.5	4275	1	42.5	3825	1	42.5	3825	1.2	37.5	4050
8 to 4	90	1.2	37.5	4050	1.2	72.5	7830	1.2	72.5	7830	1	62.5	5625
3 to 5	65	1	47.5	3087.5	1	52.5	3412.5	1	52.5	3412.5	1	47.5	3087.5
4 to 7	130	1	30	3900	1	40	5200	1	50	6500	1.2	50	7800
7 to 10	110	1	60	6600	1	40	4400	1.2	40	5280	1	50	5500
1 to 5	45	1	70	3150	1	70	3150	1	70	3150	1	60	2700
5 to 3	45	1.2	47.5	2565	1.2	52.5	2835	1.2	52.5	2835	1.2	47.5	2565
1 to 8	248	1	52.5	13,020	1	32.5	8060	1	32.5	8060	1	37.5	9300
8 to 6	80	1.2	47.5	4560	1.2	42.5	4080	1.2	42.5	4080	1	37.5	3000
6 to 4	80	1.2	40	3840	1	60	4800	1	60	4800	1.2	55	5280
1 to 4	75	1	60	4500	1	70	5250	1	70	5250	1	70	5250
5 to 9	75	1	57.5	4312.5	1.2	42.5	3825	1.2	42.5	3825	1	32.5	2437.5
8 to 3	168	1.2	30	6048	1.2	50	10,080	1.2	50	10,080	1	35	5880
3 to 7	168	1	37.5	6300	1	42.5	7140	1	32.5	5460	1	37.5	6300
Total moments		189185.5			186,820			184,593			180,723		

Table 5 (continued)

Layout analysis work sheet for 10Px10M

Move	Adjusted loads	TM (1835479 10 62)			GA (1639547 10 28)			SAA (163954 10 728)			ABC (183754 10 962)		
		Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment
Layout moment ratio		192,059/189,185.5=1.015			192,059/186,820=1.028			192,059/184,593=1.040			192,059/180,723=1.063		

onlooker bees. Each solution X_i (i=1, 2, 3, ……, F) is a D-dimensional vector. Here, D is the number of optimization parameters. After initialization, the population of the solutions is subject to repeated cycles, C=1, 2, 3, ………, C_n, of the search processes of the employed bees, the onlooker bees, and the scout bees. An employed bee changes the position in her memory depending on the visual information and tests the nectar amount of the new source, i.e., fitness value for a new solution. If the nectar amount of the new one is higher than the previous one, the bee memorizes the new position and forgets the old position.

Otherwise it keeps the position of the previous one in memory. After all employed bees complete the search process; they share the nectar information like quality of food sources, position, direction, and distance, etc., with the onlooker bees. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount. As in the case of the employed bee, it changes the position in her memory and checks the nectar amount of the candidate source. If the nectar is higher than the previous one, the bee memorizes the new position and forgets the old position.

The main steps of this ABC algorithm are stated below:

Step 1: Set the control parameters
Step 1: Randomly generate initial sequences
Step 2: Determine the total moment value for all sequences which are generated randomly
Step 3: Arrange the sequences in descending order
Step 4: Generate a new sequence by using the expression V_{ij},

$$V_{ij} = \{X_{ij} + \phi_{ij}(X_{ij} - X_{kj})\}$$

where
ϕ_{ij} denotes random number between −1 to 1;
$k \varepsilon$ {1,2,3….F} and $j \varepsilon$ {1,2,3….D}
denotes random indexes. $k \neq i$.
Swap operator is used for finding the improved sequence. The swapping of sequence for improved one is shown in Fig. 7.
Step : Calculate the probability value for each sequence, P_i.

$P_i = \frac{f_i}{\sum_{n=1}^{F} f_n}$ and calculate the total moment value

where
f_i denotes the fitness value of solution i, and
F denotes the number of food sources.

Table 6 Layout analysis work sheet for example 3

Layout analysis work sheet for 20Px12M

Move	Adjusted loads	TM (187 11 934 10 12 562)			GA (18,439 11 10 12 6752)			SAA (1856 10 11 93 12 742)			ABC (165,439 11 12 10 782)		
		Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment
1 to 2	435	1	32.5	14,137.5	1	32.5	14,137.5	1	32.5	14,137.5	1	32.5	14,137.5
2 to 6	270	1.2	42.5	13,770	1.2	57.5	18,630	1.2	47.5	15,390	1.2	37.5	12,150
6 to 7	385	1.2	30	13,860	1	40	15,400	1	35	13,475	1	40	15,400
7 to 8	180	1.2	37.5	8100	1.2	42.5	9180	1.2	52.5	11,340	1	37.5	6750
8 to 10	80	1	67.5	5400	1	67.5	5400	1	52.5	4200	1.2	47.5	4560
10 to 12	175	1	42.5	7437.5	1	32.5	5687.5	1	37.5	6562.5	1.2	42.5	8925
6 to 5	295	1.2	37.5	13,275	1	47.5	14,012.5	1.2	37.5	13,275	1	37.5	11,062.5
5 to 4	380	1.2	52.5	23,940	1.2	32.5	14,820	1	32.5	12,350	1	37.5	14,250
4 to 11	100	1.2	52.5	6300	1	52.5	5250	1.2	52.5	6300	1	52.5	5250
11 to 12	390	1	40	15,600	1	35	13,650	1	30	11,700	1	35	13,650
1 to 3	55	1	67.5	3712.5	1	52.5	2887.5	1	77.5	4262.5	1	62.5	3437.5
3 to 4	75	1	37.5	2812.5	1.2	37.5	3375	1	62.5	4687.5	1.2	37.5	3375
4 to 5	185	1	52.5	9712.5	1	32.5	6012.5	1.2	32.5	7215	1.2	37.5	8325
5 to 6	140	1	37.5	5250	1.2	47.5	7980	1	37.5	5250	1.2	37.5	6300
6 to 12	25	1.2	47.5	1425	1.2	42.5	1275	1	47.5	1187.5	1	62.5	1562.5
2 to 3	100	1.2	65	7800	1.2	50	6000	1.2	75	9000	1.2	55	6600
3 to 6	135	1	52.5	7087.5	1	37.5	5062.5	1.2	57.5	9315	1.2	52.5	8505
7 to 9	125	1	45	5625	1.2	40	6000	1.2	50	7500	1.2	50	7500
9 to 12	125	1	32.5	4062.5	1	42.5	5312.5	1	37.5	4687.5	1	32.5	4062.5
4 to 8	90	1.2	67.5	7290	1.2	37.5	4050	1.2	37.5	4050	1	42.5	3825
8 to 11	125	1	45	5625	1	60	7500	1	60	7500	1.2	65	9750
3 to 5	30	1	45	1350	1	40	1200	1.2	65	2340	1.2	45	1620
4 to 7	150	1.2	60	10,800	1	35	5250	1.2	40	7200	1	35	5250
7 to 10	30	1	60	1800	1.2	50	1800	1.2	35	1260	1.2	40	1440
1 to 5	45	1	52.5	2362.5	1	42.5	1912.5	1	42.5	1912.5	1	47.5	2137.5
5 to 3	45	1.2	45	2430	1.2	40	2160	1	65	2925	1	45	2025
8 to 12	160	1	55	8800	1	60	9600	1	60	9600	1.2	60	11,520
1 to 8	345	1	37.5	12,937.5	1	37.5	12,937.5	1	37.5	12,937.5	1	42.5	14,662.5
8 to 6	270	1	37.5	10,125	1	52.5	14,175	1	42.5	11,475	1.2	32.5	10,530
4 to 10	105	1	30	3150	1	60	6300	1.2	45	5670	1	35	3675
1 to 4	230	1	75	17,250	1	45	10,350	1	45	10,350	1	55	12,650
5 to 9	150	1.2	37.5	6750	1.2	47.5	8550	1	62.5	9375	1	52.5	7875

Table 6 (continued)

Layout analysis work sheet for 20Px12M

Move	Adjusted loads	TM (187 11 934 10 12 562)			GA (18,439 11 10 12 6752)			SAA (1856 10 11 93 12 742)			ABC (165,439 11 12 10 782)		
		Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment	Multiplier	Adjusted distance	Moment
9 to 11	150	1.2	37.5	6750	1	37.5	5625	1.2	37.5	6750	1	37.5	5625
8 to 3	40	1	60	2400	1	45	1800	1	70	2800	1.2	50	2400
1 to 6	55	1	45	2475	1	60	3300	1	50	2750	1	40	2200
6 to 8	95	1.2	37.5	4275	1.2	52.5	5985	1.2	42.5	4845	1	32.5	3087.5
8 to 5	55	1	45	2475	1	35	1925	1	35	1925	1.2	35	2310
7 to 12	120	1	47.5	5700	1.2	52.5	7560	1.2	42.5	6120	1.2	52.5	7560
5 to 10	35	1.2	52.5	2205	1.2	62.5	2625	1	47.5	1662.5	1	42.5	1487.5
10 to 11	75	1.2	52.5	4725	1.2	37.5	3375	1	37.5	2812.5	1.2	47.5	4275
2 to 5	65	1.2	50	3900	1.2	40	3120	1.2	40	3120	1.2	45	3510
6 to 4	65	1.2	60	4680	1.2	45	3510	1	35	2275	1	45	2925
1 to 9	140	1	60	8400	1	60	8400	1	75	10,500	1	70	9800
9 to 10	95	1	45	4275	1	45	4275	1.2	45	5130	1	40	3800
10 to 7	130	1.2	60	9360	1	55	7150	1	35	4550	1	40	5200
7 to 11	210	1	37.5	7875	1.2	47.5	11,970	1.2	42.5	10,710	1.2	57.5	14,490
11 to 5	210	1	30	6300	1	55	11,550	1.2	55	13,860	1.2	60	15,120
5 to 12	210	1.2	40	10,080	1.2	60	15,120	1	55	11,550	1	50	10,500
4 to 6	20	1	60	1200	1	45	900	1.2	35	840	1.2	45	1080
6 to 10	20	1.2	60	1440	1.2	45	1080	1	40	800	1	50	1000
10 to 8	20	1.2	67.5	1620	1.2	67.5	1620	1.2	52.5	1260	1	47.5	950
11 to 10	35	1	52.5	1837.5	1	37.5	1312.5	1.2	37.5	1575	1	47.5	1662.5
9 to 6	45	1	45	2025	1	30	1350	1.2	55	2970	1.2	60	3240
6 to 11	50	1.2	37.5	2250	1.2	37.5	2250	1	47.5	2375	1	67.5	3375
Total moments		356,225			351,660			349,610			348,360		
Layout moment ratio		363,140/356,225=1.019			363,140/351,660=1.032			363,140/349,610=1.038			363,140/348,360=1.042		

Step 5: Compare the new sequence with the existing sequence based on the total moment value
Step 6: Memorize the best sequence which has minimum total moment value
Step 7: The quality of the sequence not improved in many cycles; exhaust the sequence
Step 8: Produce a new sequence for exhausted sequence by using

$$X_i^j = X_{\text{mini}}^j + \text{ran}(0,1)\{X_{\text{maxi}}^j - X_{\text{min}}^j\}$$

Three control parameters are included in the proposed algorithm. The number of food sources (F), the predefined value of limit (L), and the number of cycles (C_n) for searching food source (C) are the parameters.

Step 9: No improvements in the quality of the sequence up to it reaches the maximum number of cycles
Step 10: Store as a final sequence, otherwise go to step 2

Figure 8 illustrates the step-by-step procedure of ABC algorithm.

In ABC algorithm, each cycle consists of three important stages.

Stage 1 Sending the employed bees onto their food sources and evaluating their nectar amounts.

- Food sources are randomly selected and the nectar amount is determined.
- Sharing the nectar information of the sources with the onlooker bees.
- Then every employed bee goes to the food source area already visited.
- Employed bee chooses a new food source by means of visual information in the neighborhood and evaluates its nectar amount.

Stage 2 After sharing the nectar information of food sources, the selection of food source regions by the onlookers and evaluating the nectar amount of the food sources.

- An onlooker prefers a food source area depending on the nectar information distributed by the employed bees.
- Onlooker chooses a new food source in the neighborhood of the one in the memory depending on visual information given by employed bees.
- Determination of the new food source is carried out by the bees based on the comparison process of food source positions visually.
- When the nectar of a food source is abandoned by the bees, a new food source is randomly determined by a scout bee and replaced with the abandoned one.

Stage 3 Determining the scout bees and then sending them randomly onto possible new food sources.

In this algorithm, one scout goes outside for searching a new food source and the number of employed and an onlooker bee is selected to be equal to each other. These three steps are repeated through a predetermined number of cycles (C_n) or until a termination criterion is satisfied.

6 Pseudo code of ABC algorithm

A pseudo code of ABC algorithm adopted for solving fixed area layout problem is shown in Fig. 9.

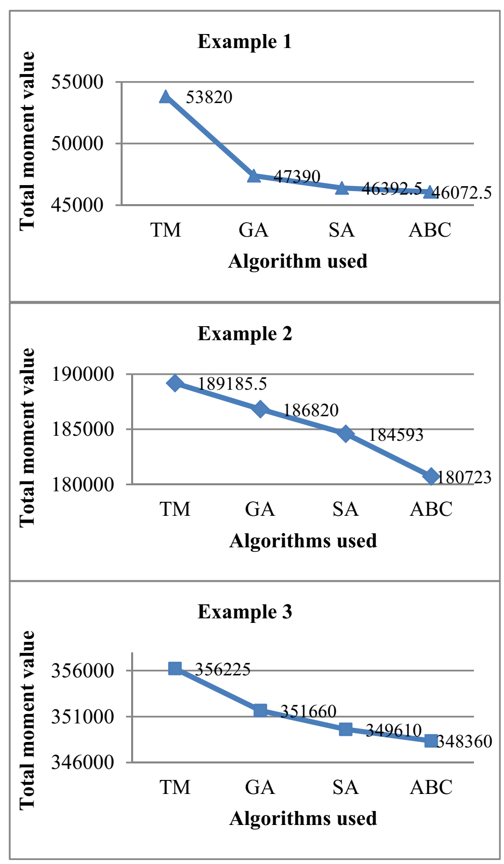

Fig. 10 Comparison of total moment value obtained by various algorithms

7 Control parameters of ABC algorithm for example 1

Each instance can be characterized by the following parameters:

Number of jobs/parts, $Np=3$;
Number of machines, $M=8$;

The following are the detailed parameters value:

The size of the population is equal to the number of employed bee and the number of onlooker, which is set to $20*Np$;
Size of the population=number of colony size= $20*Np=20*3=60$ (employed bees+onlooker bees);
The number of food sources equals the half of the colony size=60/2=30;
Size of the employed bees or onlooker bees, $F=30$;
The maximum cycle of the algorithm is set to $100*Np*M$;
C_n=maximum number of cycle=$100*Np*M$= $100*3*8=2400$;
The limit number of cycles through which no improvement occurs on the food source, then the employed bee becomes a scout bee; the limit number is set to $5*Np*M$;

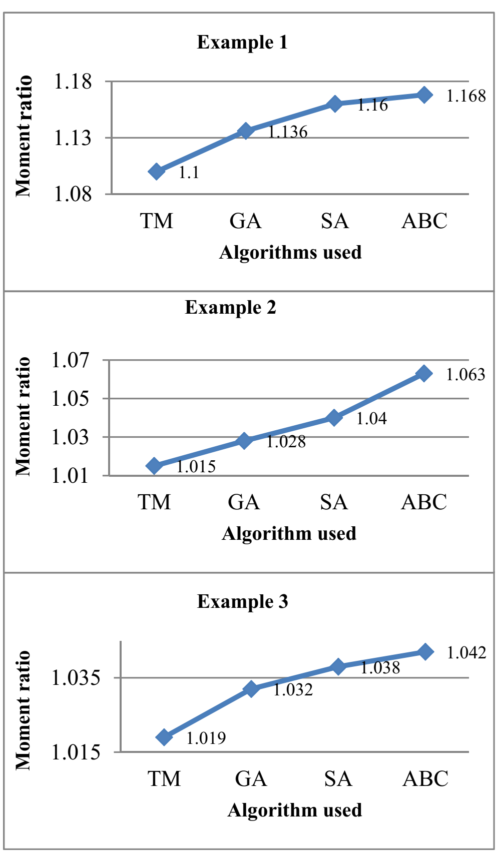

Fig. 11 Comparison of layout moment ratio of various algorithms

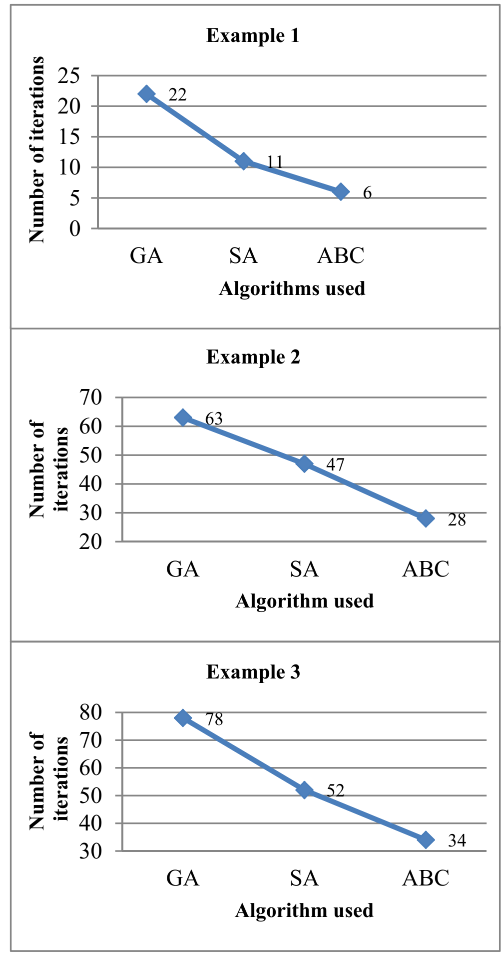

Fig. 12 Comparison based on number of iterations

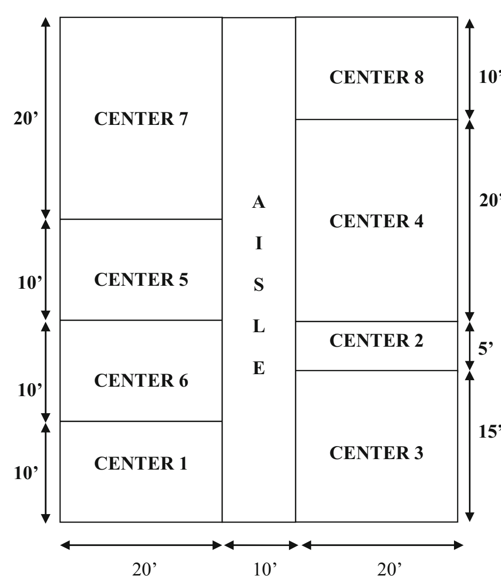

Fig. 13 Optimum layout obtained using ABC

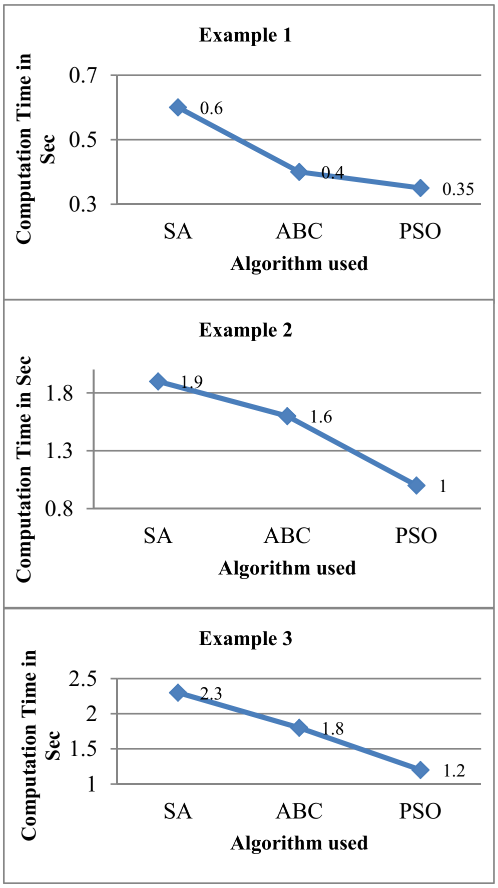

Fig. 14 Comparison of computation time between algorithms

Limit number, $L=5*M*Np=5*8*3=120$;
The percent of scout bee is set to a random number between 0.05 and 0.1;
ϕ_{ij} denotes the random number between −1 to 1=0.05 to 1.

Similarly, the control parameters are selected for other problems, i.e., example 2 and example 3.

8 Layout moment ratio

While the moments themselves provide the key to path improvement, it is often desired to measure the overall value of a layout in some manner. Perhaps as suitable a way as any is to take the ratio of the total moment for the original or existing layout to the total moment for the proposed layout. This "layout moment ratio" will serve as a way to compare the different proposed layouts if the original layout's moment is always used as the numerator. The larger layout moment ratio is more desirable layout for all applications.

9 Results and comparison

Results were summarized in Tables 4, 5, and 6 for the various sizes of fixed area cellular layout problems. The total moment value and layout moment ratio obtained by using traditional method (TM), GA, and SA algorithm were compared by Saravanan and Arulkumar [47]. They concluded that SA algorithm has given a better result than GA. Arulkumar and Saravanan [48] also compared particle swarm optimization (PSO) algorithm with TM, GA, SA, and ABC. Finally, they concluded the PSO algorithm is able to achieve better results than TM, GA, SA, and ABC for small-size problems only. It is not suitable for large-size problems. PSO has been recognized as an evolutionary computation technique and evolution strategy.

Table 7 Comparison of algorithms based on four main factors for examples 1, 2, and 3

Problem size	Comparison factors	Traditional method (TM)	Genetic algorithm (GA)	Simulated annealing algorithm (SAA)	Artificial bee colony algorithm (ABC)
3Px8M	Total moment	48,370.0	47,390.0	46,392.5	46,072.5
	Moment ratio	1.1	1.136	1.16	1.168
	No. of iterations	–	22	11	6
	Computation time	–	1.4	0.6	0.4
10Px10M	Total moment	189,185.5	186,820.0	184,593.0	180,723
	Moment ratio	1.015	1.028	1.040	1.063
	No. of iterations	–	63	47	28
	Computation time	–	1.9	1.6	1.0
20Px12M	Total moment	356,225.0	351,660.0	349,610.0	348,360.0
	Moment ratio	1.019	1.032	1.038	1.042
	No. of iterations	–	78	52	34
	Computation time	–	2.3	1.8	1.2

In this article, the total moment value and moment ratio value were obtained through ABC technique and were compared with the values calculated using GA, SA algorithms for three various sizes of benchmark problems. The higher total moment value is obtained in traditional method. The lower value is obtained in ABC algorithm. When comparing to the total moment value, the lower value is desirable for designing the layout. Some literatures motivate to implement the ABC algorithm to design and optimize the layouts. Karaboga and Akay [49] have concluded that the proposed ABC algorithm has the ability to get out of a local minimum and can be efficiently used for multivariable, multimodal function optimization.

This technique has more desirable aspects than ACO technique. In ACO technique, ants use pheromones for backtracking the route to food source, but bees use path integration. Also bees are able to compute their present location from past trajectory continuously. So it can return home through direct route and the path emerging is faster. This algorithm is more efficient in finding and collecting food, which is it takes less number of steps. It is more scalable and it requires less computation time to complete the task.

So ABC is selected for solving a fixed area cellular layout design problems. In this work, different results were obtained using TM, GA, SA, and ABC. The differences between the above methods were found out and the best method for the layout design as well. The total moment values were compared using graphical representation for three examples in Fig. 10. Based on the comparison of total moment value, ABC algorithm gives better result than the other techniques for three problems, i.e., 3Px8M, 10Px10M, 20Px12M.

Figure 11 shows the comparison of total moment ratio obtained by TM, GA, SA, and ABC. The larger layout moment ratios 1.168, 1.063, and 1.042 are obtained in ABC algorithm. The proposed layout which has the highest layout moment value is a more desirable layout or close to optimum layout. Three different results were obtained using GA, SA, and ABC algorithms. The differences between the above methods were found out and the best method for the layout design as well. The coding for the proposed method was developed on C programming language platform. A laptop with Intel Core Duo2 @1.66 GHz and 1 GB of RAM was used for conducting the experiments and for determining the required execution time.

While using GA for example 1, close to optimum result was obtained after 22 iterations and found that the least total moment value is 47,390. The layout moment ratio is 1.136. The corresponding sequence of the above value is 1 2 3 4 8 5 6 7. The average computational time (CPU) taken is 1.40 s. In SA, the least total moment value is 46, 392.5 for the new sequence 1 6 5 7 8 4 3 2 and the computation time is 0.60 s for 11 iterations.

It has slightly higher layout moment ratio 1.168 than GA's ratio. The number of iterations for the optimum result obtained by various algorithms for three problems is shown in Fig. 12, and the ABC algorithm, given the best result with less number of iterations and CPU time on an average, is 0.40 s. For example 1, the least total moment value of 46,072.5 is obtained for the new sequence of 1 6 5 7 8 4 2 3 as shown in Fig. 13.

The comparison of average computation time for each technique is shown in Fig. 14. It may be the optimum sequence obtained by ABC algorithm with minimum computation time. It has higher moment ratio of about 1.168. Table 7 shows the comparison between various algorithms for the three benchmark problems based on the main factors which are affected the layout design.

The conclusion of this article is that ABC is a better non-traditional optimization algorithm for designing fixed area cellular layout for various sizes than SA and GA. So ABC may be the best optimization technique suitable for solving the fixed area layout problems among the above-said algorithms.

10 Span of potential

This work leaves scope for further research leading to further improvement in global optimization, and the algorithm can be implemented in multiple cells. The other non-traditional optimization algorithms like PSO, ACO, swarm intelligence (SI), scatter search (SS), and taboo search (TS) are to be used in order to optimize and converge to the results nearer to optimum. In this work, only two factors are considered and other factors like product volume, lead-time, material-handling system, and manufacturing cost may be considered in the future. Also, the size (number of machines and number of parts) of the problem may be increased.

11 Conclusion

To identify best algorithm by comparing the results of some non-traditional optimization algorithms for fixed area cellular layout problems is the main objective of this article. The ABC algorithm is capable to produce better results than other techniques like TM, GA, and SA. This article leads to a conclusion that the developed procedures in this article can be suitably modified to a large number of parts with different sequences and a large number of machines with fixed area. This method is suitable for large-size problems. This system gives best placement of machines in few seconds. The conclusion of this article is that ABC is a better non-traditional optimization algorithm for design and optimization of fixed area cellular layout problems than GA and SA. Also, it is the technique used to design and optimize the layout problems in minimum time.

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