2011 International Conference on Economics and Business Information
IPEDR vol.9 (2011) © (2011) IACSIT Press, Bangkok, Thailand

Multi-row Machine Layout Design using Aritificial Bee Colony

Ponpimon Soimart[1] and Pupong Pongcharoen[2,+]

[1]Faculty of Science and [2]Faculty of Engineering, Naresuan University, Pitsanulok, 65000 Thailand

Abstract. Machine layout design (MLD) problem usually arises when a company considered on the total transportation distance required for manufacturing multiple products to be performed on a predefined sequence of machines located in a shop floor area. The problem is known to be NP hard problem and usually solved by metaheuristics. The paper presents the development of an automated MLD programming tool that apply Artificial Bee Colony (ABC) algorithm and reports the influence of ABC's parameters configuration on its performance. The program was coded in modular style and tested using five benchmarking datasets adopted from literature. The experimental results indicated that the ABC performance can be improved dramatically after adopting the optimum parameter setting.

Keywords: Artificial Bee Colony, Machine Layout, Metaheuristics, Multiple rows, Design of Experiment.

1. Introduction

The placement of the machines in the manufacturing area, also referred to "machine layout problem", is known to have a significant impact upon manufacturing costs, work in process, lead times and productivity [1]. The primary objective of machine layout problems is to obtain the most effective machine arrangement and the path of material flow so that the overall manufacturing cost (usually including machining cost plus the material handling cost) is minimised. The machine layout problem is a combinatorial optimisation problem and also classified as Non-deterministic polynomial (NP) hard problem [2], which means that the amount of computational time required to find solutions increase exponentially with problem size. This paper focused on the multiple-row machine layout design for flexible manufacturing of multiple products. Flexible manufacturing system is a mid-variety and mid-volume production system that lies between mass production and customised production.

Various assumptions have been made in order to simplify, formulate and solve machine layout problems. The most common assumption can be summarised as follows: machines and manufacturing area are rectangular shape; machine operates at centriod; machines must be arranged within the area and also parallel to its side walls; materials or parts flow between machines can move either from left to right or right to left, top to bottom or bottom to top; transfer time is not taken into account; and each machine can handle only one part at a time.

The objectives of this paper were to: i) present the development of the Artificial Bee Colony algorithm for designing machine layout; and ii) investigate the appropriate parameter setting of the proposed method using statistical tools for experiment design and analysis.

The remaining sections in this paper are organised as follows. Section 2 presents a brief introduction on machine layout problem and its mathematical model. Section 3 describes the process of the Artificial Bee Colony (ABC) algorithm and its pseudo code for designing machine layout. Section 4 presents the experimental design and provides a statistical analysis on the experimental results and finally followed by the conclusions in section 5.

+ Corresponding author. Tel.: + 66 55 964201; Fax: + 66 55 964003
E-mail address: pupongp@nu.ac.th; pupongp@yahoo.com

2. Multiple-Row Machine Layout Problem

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 flows between machines corresponding to its sequence. The most common objective for designing machine layout is to minimise the total transportation distance of materials or parts to be performed on machines arranged in the manufacturing area.

Previous research relating to machine layout problem has been focused on the application of metaheuristics e.g. Genetic Algorithm [3] Ant Colony Optimisation and Shuffled Frog Leaping [4]. The mathematical model and notations for the machine layout problem is as follows:

$$\text{Total Distance } = \sum_{i=1}^{M}\sum_{j=1}^{M}\sum_{h=1}^{M-1}\sum_{l=h+1}^{M}\sum_{u=1}^{Norow}\sum_{v=1}^{Norow}(f_{ij} + f_{ji})D_{hulv}\,x_{ihu}\,x_{jlv} \qquad (1)$$

Subject to:

$$\sum_{h=1}^{M}\sum_{u=1}^{Norow} x_{ihu} = 1 \qquad \forall i \qquad (2)$$

$$\sum_{i=1}^{M} x_{ihu} \le 1 \qquad \forall h,u \qquad (3)$$

$$x \in \{0,1\} \qquad (4)$$

Where f_{ij} and f_{ji} are the frequency of material moved from machine i to j and machine j to i. D_{hulv} is the distance from the centroid of machine i at position h in row u to the centroid of machine j at position l in row v. x_{ihu} is equal to 1 if machine i is located at position h in row u. and x_{jlv} is equal to 1 if machine j is located at position l in row v. This mathematical model has been derived to describe the multiple row machine layout problem. The objective function (1) is total distance of material handling. Constraint (2) a machine can be arranged only a position. Constraint (3) a position can arrange only on a machine. Constraint (4) define x to be 1 or 0 only.

3. Artificial Bee Colony (ABC) Algorithm

Since nature is always a source of inspiration, there has been increasing interests in development of computational models or methods that iteratively conduct stochastic search process inspired by natural intelligence. Many optimisation algorithms have been designed and developed by adopting a form of biological-based swarm intelligence including Artificial Bee Colony (ABC) algorithm. The honey bee swarm is a good example of well known social insects. The minimal model of foraging selection that leads to the emergence of collective intelligence of honey bee swarms consists of three essential components: food sources, employed foragers and unemployed foragers. There are two basic behaviours, recruitment to a food source and the abandonment of a food source [5].

The colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts. First half of the colony consists of employed artificial bees and the second half includes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to number of food sources. The bee of an abandoned food source becomes a scout [6]. The main step of the ABC algorithm including initialisation of population, place the employed bees on their food sources, place the onlookers on the food sources depending on their nectar amounts, send the scouts to search area for discovering new food source and finally update the best food source found so far. The food source searching process is repeated until termination criteria are satisfied [7].

In ABC algorithm, there are three control parameters including i) the number of food sources (B), which is equal to the number of bees; ii) the predefined value of limit (L) for unimproved loop in the case that if a position cannot be improved then food source is assumed to be abandoned; and finally iii) the number of cycles for searching food source (C). These control parameters play an important role on the performance of the ABC algorithms. Enhancing the algorithm's performance can be basically accomplished by the use of the appropriate parameter setting, which can be systematically investigated and statistically identified via the experimental design and analysis [9]. Due to the nature and complexity of the problem domains, it has been suggested that the appropriate parameter setting can varied across problem sizes and/or problem domains.

Most research work related to the application of nature inspired algorithms e.g. Genetic Algorithm has set its parameters and operators in an ad hoc fashion [10].

Employed bees and onlookers find a new food source V_i in the neighbourhood of its current food source X_i by formula (5) that call "improve bees". In this work, the swap operator (SO) [8] is used for improving bees. Where i and $k \in \{1, 2, \ldots B\}$, $k \neq i$ and θ is a random number between [-1, 1]. For the swap operator, $\theta(X_i - X_k)$ is distance between X_i and V_i, $(X_i - X_k)$ is all position pair for swapping. Multiply result of all position pair' amount and θ is constraint, which is the position pair' amount for swapping of V_i is shown in Fig. 1.

$$V_i = X_i + \theta(X_i - X_k) \tag{5}$$

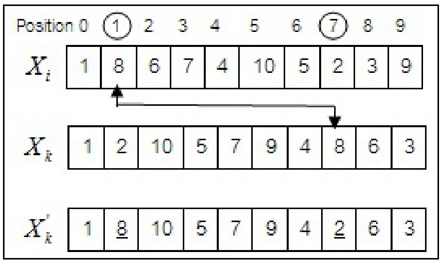


Fig. 1: A new food source by swap operator

The pseudo code of ABC algorithm applied to solve the machine layout problem is shown in Fig. 2. The ABC base Machine Layout Design Tool (ABCMLDT) was coded in modular style using a general purpose programming language called TCL/TK [11]. The ABCMLDT developed can be categorized into three phased: i) input phase, in which number of machines, width and length of machines, number of products and machines sequence of products were upload into the program; ii) machine layout phase, where the proposed ABC algorithm were used to arrange machines and calculate total distance of the material handling; and iii) output phase including information on the best layout found and its minimised total distance of the material handling. Graphic user interface (GUI) was considered during the development of the program to allow users to manipulate data, set parameters and choose outputs from the program.

```
Define number of bees (B), number of cycles (C) and unimproved cycle (L)
Initial the population of layouts (Xi); i = 1, 2, 3, …, B.
Evaluate the population
Set cycle = 1
Repeat
   Produce new layouts (Vi) as the employed bees and evaluate them
   Apply greedy selection process for the employed bees
   Calculate the probability value (Pi) for layouts
   Produce new layouts (Vi) as the onlookers from Xi selected depending on Pi 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
```

Fig. 2: Pseudo code of the ABC algorithm adopted from [7].

4. Experimental Design and Analysis

This section presents the design and analysis of sequential experiment conducted using the ABC algorithm. A notebook computers with Core i5 2.40 GHz CPU and 2GB DDRIII RAM was used for conducting the experiments and for determining the execution time required for each computational run. The screening experiment was firstly carried out by using full factorial experimental design (3^k) [14] for systematically investigating the appropriate parameter setting of ABC algorithm. This experiment was based on a benchmarking machine layout problem adopted from [12], which involves thirty non-identical machines for manufacturing ten products. The experimental factors and its levels considered in this work was summarised in table 1.

Table 1: Experimental factors and its levels.

Factor	Levels	Uncoded Value		
		Low (-1)	Medium (0)	High (1)
BC	3	25*100	50*50	100*25
L	3	10	30	50

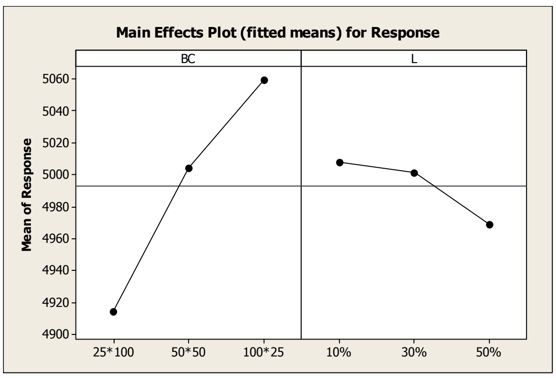
From table 1, there are two factors, each of which is considered at three levels. The former factor is the combination of the number of bees (*B*) and number of cycles (*C*) for searching food sources. This combination of both parameters plays an important role on the amount of search in the solution space conducted by the algorithm. Higher values of both parameters increase the probability of finding the best solutions but require longer computational time. If there is no timing constraint, the values of both parameters should be defined as high as possible. However, time is always a constraint. In this work, the amount of search (a combination of *BC*) for the instants problem is predefined at 2,500. The latter factor is the predefined value of limit (*L*) for unimproved cycle in the case that if a position cannot be improved then food source is assumed to be abandoned. Solving non-linear mathematical functions [7], the limitation has been set to the number of food source multiplied by the dimension of the problem considered. In this case, the machine layout problem has no dimension. The limitation was therefore defined as percentage according to the number of cycles (*C*). The values of the parameter were investigated between 10-50% of the number of cycles (*C*) [13].

The full factorial experimental (3^2) design [14] was carried out with five replications using different random seed numbers [4]. The computational results obtained from 45 (3^2*5) runs were analysed using a general linear model form of analysis of variance (ANOVA). Table 2 shows ANOVA table consisting of Source of Variation, Degrees of Freedom (*DF*), Sum of Square (*SS*), Mean Square (*MS*), *F* and *P* values. A factor with value of $P \leq 0.05$ was considered statistically significant with 95% confidence interval.

Table 2: ANOVA on the ABC's parameters.

Source	DF	SS	MS	*F*	*P*
BC	2	160600	80300	21.12	0.000
L	2	13211	6606	1.74	0.192
*BC**L*	4	41636	10409	2.74	0.046
Error	32	121641	3801		
Total	44	342527			

From ANOVA table, it can be seen that all ABC algorithm's parameters (*BC* and *L*) were statistically significant either in form of main effect or interaction between parameters. The combination of the number of bees and number of cycles (*BC*) for searching solutions was found significant as main effect. The main effect plots shown in Fig. 3 indicated that the best layouts were obtained from the ABC algorithm when the BC was set at 25*100. Another parameter, the number of limits (*L*), was almost significant in main effect but was significant in the interaction effect with 95% confidence interval. The interaction effect plots of the ABC algorithm shown in Fig. 4 indicated that if the *BC* parameter was set at 25*100 then the *L* parameter should be set at 50% of number of cycles (*C*). As far as the computational time is concerned, the execution time required for each experimental run was recorded. It was found that the average execution time taken by the proposed algorithm was about 9.19 min.



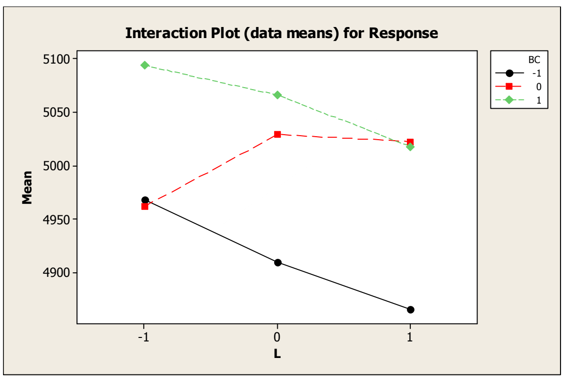


Fig. 3: Main effect plots of the ABC algorithm. Fig. 4: Interaction plots of the ABC algorithm.

A further experiment was carried out by adopting the appropriate parameter setting obtained from previous experiment for solving five benchmarking datasets including ten machines and three products (M10P3), M20P5, M15P9, M30P10 and M30P27. For each problem, the computational runs were repeated 30 times using different random seed generators. The minimum, maximum, mean, standard deviation and average execution time of the experimental results for each problem with optimum and other parameter's ABC algorithm are summarised in table 3. It can be seen that the optimum parameter's ABC algorithm find better solutions than other parameter's ABC algorithm for all problem sizes. The average execution time required for the large problem was longer than the small problem. However, it should be noted that the appropriate parameter setting may be dissimilar for different problem sizes.

Table 3: Computational results on five benchmarking datasets.

Results (meter)	M10P3		M20P5		M15P9		M30P10		M30P27	
	Appropriate	Other	Appropriate	Other	Appropriate	Other	Appropriate	Other	Appropriate	Other
Min	186.975	186.975	1262.350	1280.750	1353.850	1371.749	4727.724	4938.675	10000.350	10000.750
Max	190.975	193.775	1443.650	1449.250	1446.850	1472.449	5120.375	5163.875	10027.550	10065.100
Mean	188.061	189.348	1376.266	1394.153	1406.863	1426.876	4937.756	5031.783	10008.558	10020.420
SD	1.245	1.871	40.025	40.437	25.877	24.127	89.385	63.999	7.897	18.873
Time(min.)	1.15	1.15	2.38	3.32	2.16	2.17	5.02	5.03	6.61	6.57

5. Conclusions

The design task on machine layout problem is to assign machines to locations within a given layout in such a way that a given performance measure is optimised. The most famous performance measure is the minimisation of material handling distance. This paper presents the development of the Artificial Bee Colony (ABC) based designing program for solving multiple-row non-identical machine layout problem. The program was tested using five different sizes of datasets. The analysis on the experimental results indicated that the algorithm's performance can be improved significantly after adopting the optimum parameter setting identified through statistical design and analysis.

6. Acknowledgements

The corresponding author would like to acknowledge the Faculty of Engineering, Naresuan University for financial support.

7. References

[1] A. Dira, H. Pierreval and S. Hajri-Gabouj. Facility Layout Problems: A Survey. Annual Reviews in Control. 2007, 31(2): 255-267.

[2] R. Sarker and et al. An Evolutionary Algorithm for Machine Layout and Job Assignment Problems. Evolutionary Computation. 2007, 9(1): 3991-3997.

[3] M.A. El-Baz. A Genetic Algorithm for the Facility Layout Problems of Different Manufacturing Environments. Computers and Industrial Engineering. 2004, 47(2-3): 233-246.

[4] N. Leechai, T. Iamtan and P. Pongcharoen. Comparison in Rank-base Ant System and Shuffled Frog Leaping for Designing Multiple Row Machine Layout. SWU Engineering Journal. 2009, 4(2): 102-115.

[5] L. Bio and J. Zeng. Comparison and Analysis of the Selection on Mechanism in the Artificial Bee Colony Algorithms. Hybrid Intelligent System. 2009, 9(1): 411-416.

[6] D. Karaboga and B. Basturk. On Performance of Artificial Bee Colony (ABC) Algorithm. 2008, 8(1): 887-697.

[7] D. Karaboga and B. Akay. A Comparative Study of Artificial Bee Colony Algorithm. Applied Mathematics and Computation. 2009, 214(1): 108-132.

[8] H. Nazif and L.S., Lee. A Genetic Algorithm on Single Machine Scheduling Problem to Minimise Total Weighted Completion Time. European Journal of Scientific Research. 2009, 35(3): 444-452.

[9] P. Pongcharoen, W. Chainate and P. Thapatsuwan. Exploration of Genetic Parameters and Operators through

Travelling Salesman Problem. Science Asia. 2007, 33: 215-222.

[10] H. Aytug, M. Knouja and F.E. Vegara. Use of Genetic Algorithms to Solve Production and Operation Management Problem: A Review. International Journal of Production Research. 2003, 41: 3955-4009.

[11] J.K. Ousterhount. Tcl and the Tk Toolkit. Addison-wesley, 1994.

[12] A.C. Nearchou. Meta-heuristics from Nature for the Loop Layout Design Problem. International Journal of Production Economics. 2006, 1012(1): 312-328.

[13] P. Pansuwan, N. Rulwong and P. Pongcharoen. Identifying Optimum Artificial Bee Colony Algorithm's Parameter for Scheduling the Manufacture and Assembly of Complex Products. Computer and Network Technology. 2010, 2(1): 339-343.

[14] D.C. Montgomery. Design and Analysis of Experiments. John Wiley&Sons, 2001.