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Full Length Research Paper

Facility layout design for hybrid cellular manufacturing systems

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Facility layout which is the arrangement of facilities in the shop-floor has a great impact on the performance of manufacturing systems. An effective layout decreases material handling cost, throughput time, lead-time and results in increasing productivity and efficiency of manufacturing systems. Although layout problems have significant roles on the efficacy of manufacturing systems, scant attention has been paid to the layout design in hybrid cellular manufacturing systems. In this paper, a mathematical model for layout problems in a hybrid cellular manufacturing system is proposed that minimizes the total material handling cost (both inter-cell and intra-cell material handling cost). To solve the model, a variant of a simulated annealing algorithm is developed. The results show that the developed algorithm outperforms the algorithm that was benchmarked from the literature in terms of solution quality and computation time.

Key words: Hybrid cellular manufacturing, facility layout, simulated annealing.

INTRODUCTION

Facility layout problem (FLP) is how to arrange facilities included machines, tools, instruments, work centers, departments and warehouses according to the relationships that exist between them (Aiello et al., 2006). The main aim of layout problems is to find the most efficient arrangement of facilities within a shop floor (Krishnan et al., 2009). FLP plays an important role on the efficacy of every manufacturing system. A good placement of facilities can decrease up to 50% of operating expenses (Tompkins et al., 1996) and facilitate the production process and promote utilization of manpower while a poor facility layout design decrease the system performance and customer satisfaction (Ramkumar et al., 2009). In contrast to the importance of layout problems, it has rarely absorbed the attention of researchers in the design of cellular manufacturing systems (Sangwan and Kodali, 2009, Ariafar and Ismail, 2009).

Cellular manufacturing system (CMS) is a successful application of group technology. It seeks the similarity in parts and determines part families based on their similarities and dedicates each part family to a machine cell to be produced (Noktehdan et al., 2010). It has been shown in the literature that implementation of a CMS has improved quality of products while decreased material handling cost, work in process, setup time, lead time and throughput time (Wemmerlov and Johnson, 1997, Wemmerlov and Johnson, 2000).

Cellular manufacturing system is implemented to increase the efficiency and productivity of manufacturing systems (Tursel and Levent, 2008), but it does not perform well in every situation (Assad et al., 2003, Fraser et al., 2007). Hence, the use of a full implementation of CMS may not be desirable in all industries (Harhalakis et al., 1996) specially when the variability and uncertainty, of demand is high. In this situation, usage of a hybrid cellular manufacturing system (HCM) is reasonable (Satoglu and Suresh, 2009). An HCM is a layout in which a coexistence of a functional layout and cellular manufacturing system comprises the benefits of both layouts

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(Shambu and Suresh, 2000). Hybrid cellular manufacturing despite its widespread usage, in practice has addressed only in limited past studies (Feyzioglu and Pierreval, 2009, Satoglu and Suresh, 2009).

Delaney et al. (1995) were one of the first who proposed a method for design of a hybrid manufacturing system. The objective of their model was to minimize inter-cell material handling cost and to maximize intra-cell directional material flow. Harhalakis et al. (1996) presented an approach for design of a hybrid manufacturing system which was consisted of machine cells and job shops. Their method took into account machine capacities, similarity in setup and sequence of operations. Venkataramanaiah and Krishnaiah (2002) developed a hybrid heuristic method for fractional cell formation. Their approach designed complete cells if possible and in existence of exceptional part/operations, a combination of regular cells and a reminder cell was applied.

Viguier and Pierreval (2004) proposed a constrained multi-criteria approach in order to design a hybrid manufacturing system. Ioannou (2006) proposed a method for converting pure functional manufacturing shops into hybrid production systems, that was composed of both cellular and functional layouts. In (Venkumar and Haq, 2006a, Venkumar and Haq, 2006b), fractional cell formation was solved by a neural network. The problem addressed in (Feyzioglu and Pierreval, 2009) was how to allocate machines and products to design such systems that take advantages of both functional layout and cellular manufacturing system. Satoglu and Suresh (2009) proposed a goal programming model to design a hybrid manufacturing system, in a dual resource constrained settings.

The objective of this paper is to develop a mathematical model for a layout problem in hybrid cellular manufacturing systems that minimizes the total material handling cost (both inter-cell and intra-cell). The rest of the paper is organized as follows. The mathematical model is presented in section 2. The developed SA algorithm is proposed in section 3, followed by computational results in section 4, and finally section 5 provides the conclusion.

Problem formulation

In this section, a mathematical model for layout problem in a hybrid manufacturing system is presented, which dealt with both inter-cell and intra-cell material handling cost. The hybrid manufacturing system is a manufacturing system that contains some regular cells and a reminder cell, which caters to the needs of exceptional parts/operations in the system. In this model, it is assumed that the cell formation stage has completed beforehand and the composition of cells and type of machines has determined and known as a prior. The model arranges the machines in a hybrid manufacturing system in order to minimize the total material handling cost.

Sets and indices

The indices, parameters and variables of the model are defined as follows:

i,k : Indices for locations

j,l : Indices for machines

m,n : Indices for machine cells

n_m : Number of machines and available machine locations in the manufacturing system

n_c : Number of machine cells available in the system

MF_{jl} : Material flow between machine j and machine l

C_{jl} : Unit distance cost between machine j and machine l

D_{ik} : Distance between location i and location k

$NMC\ (C_m)$: Number of machines that belongs to the machine cell (C_m)

$$X_{ij} = \begin{cases} 1 & \text{If machine } i \text{ is assigned to machine location } j \\ 0 & \text{Otherwise} \end{cases}$$

$$Y_{im} = \begin{cases} 1 & \text{If machine } i \text{ belongs to the machine cell } C_m \\ 0 & \text{Otherwise} \end{cases}$$

Mathematical model

The facility layout problem for a hybrid manufacturing system is formulated as follow:

$$Min \sum_{i=1}^{n_m} \sum_{j=1}^{n_m} \sum_{k=1}^{n_m} \sum_{l=1}^{n_m} \sum_{m=1}^{n_c} \sum_{n=1}^{n_c} MF_{jl} C_{jl} D_{ik} X_{ij} X_{kl} Y_{im} Y_{kn} \tag{1}$$

$$\sum_{i=1}^{n_m} X_{ij} = 1 \qquad j = 1, \ \ldots, n_m \tag{2}$$

$$\sum_{j=1}^{n_m} X_{ij} = 1 \qquad i = 1, \ \ldots, n_m \tag{3}$$

$$\sum_{m=1}^{n_c} Y_{im} = 1 \qquad i = 1, \ \ldots, n_m \tag{4}$$

$$\sum_{i=1}^{n_m} Y_{im} = NMC(C_m) \qquad m = 1, \ \ldots, n_c \tag{5}$$

The objective function (1) minimizes the total material handling cost (both inter-cell and intra-cell) on the shop. Constraints (2) and (3) ensure that each machine is only assigned to one machine location, and to each machine location merely one machine is assigned. Then constraints (4) and (5) ensure that each machine is only assigned to one machine cell, and to each cell assigns the same number of machines belongs to that machine cell.

METHODOLOGY

Facility layout problem is a nondeterministic polynomial hard time problem (Enea et al., 2005). Hence, the use of a meta-heuristic method to solve the problem is reasonable. One of these methods is simulated annealing (SA). It is a widely used technique in optimization of sophisticated combinatorial problems (Kuo, 2010) which was introduced by (Kirkpatrick et al., 1983), and independently by (Černý, 1985). The concept of SA is based on physical annealing (Abdullah et al., 2011), which is a heat treatment process that gradually cools a physical system to reach to a state of a minimum potential energy. In SA, feasible solutions act like the states of a physical system and the objective function which should be minimized is equivalent to the energy of a state. The SA algorithm, in the searching process not only accepts better neighbouring solutions but also worse ones with a certain probability. This results in escaping the algorithm from local optimum solutions. Therefore, SA has the potential to find high quality solutions not too dependent on the initial solution compared to the local search algorithms.

In this study, a variant of a simulated annealing algorithm is adapted to search for an optimal layout which minimizes the total material handling cost (both inter-cell and intra-cell material handling cost). The objective function of the algorithm calculates the material handling cost. The proposed SA algorithm is equipped with a procedure to build an initial layout and a mechanism for generating alternative layouts. The proposed simulated annealing algorithm will be explained in the next sections.

Initial layout

In the proposed algorithm, at first each cell is arranged randomly then in each cell a random arrangement of machines forms the layout of machines within cells to configure the initial layout. In the initial configuration, all the machines of each machine cell arrange in the same machine cell so it leads to a feasible layout of machines, and satisfies the zoning constraints of the problem.

Mechanism of generating alternative layout

To generate an alternative layout (neighbouring solution), the proposed algorithm uses the following two procedures as follows:

1. Select two cells randomly and swap the location of them;
2. Choose cells randomly and exchange the location of two machines in the selected cell.

Both procedures produce feasible layouts. The proposed mechanism for generating alternative layout in this study after determining the arrangement of cells, arrange the machines within cells randomly while in a previous work by authors (Ariafar and Ismail, 2009), the algorithm arranged the machines within cells in an orderly manner.

Initial temperature

Initial temperature (T0) should be high enough to avoid a premature convergence (Raza and Akgunduz, 2008) and provide a random search of the solution space. Random search results in acceptance of worse solutions (Uphill move) with a certain probability and leads the algorithm not to trap in local optimums.

The Epoch length

Equilibrium condition implies that in current temperature, the value of objective function cannot be improved anymore and the epoch length ( ) refers to the number of trials over which the annealing process reaches thermal equilibrium (the temperature remains unchanged). In this study, epoch length is calculated by the following equation:

$$L = LP * Q^2 \qquad 0 < LP < 1 \tag{6}$$

In the above equation (LP) is one of the parameters of algorithm and (Q) is the number of cells when SA algorithm searches for the arrangement of cells and is considered the quantity of machines when it searches for the layout of machines.

Temperature reduction function

In implementation of SA algorithm, the initial temperature decreases according to the temperature reduction function in order to decrease the probability of acceptance of worse solutions (making uphill move). In this study, temperature is decreased by the following simple geometric function.

$$T_k = rT_{k-1} \qquad k = 2,3,... \quad 0 < r < 1 \tag{7}$$

In the above equation (r) is the decrement rate.

Stopping criterion

The annealing process is terminated when the value of the objective function does not improve for a certain number of consecutive epoch lengths. In this paper, stopping condition (Stp) is considered as the number of temperature reduction steps that current solution remains unchanged and no neighboring solution is accepted.

RESULTS AND DISCUSSION

In this paper, in order to verify the validity of the proposed SA algorithm, the results are compared to the benchmarked algorithm from the literature that was developed by (Wang et al., 1998). Both algorithms (proposed algorithm and algorithm adapted from the literature) are programmed in C/C++ language and several test problems are generated randomly. Then, the parameters of both algorithms are tuned based on one of the test problems (problem with five cells and twenty machines) and the rests are solved by algorithms with tuned parameters. The results of two algorithms are compared in terms of solution quality and computation

Table 1. Tuned parameters for proposed algorithm.

Parameter	Inter-cell layout	Intra-cell layout
T0	250	15
LP	0.50	0.45
r	0.90	0.95
Stp	8	7

Table 1. Tuned parameters for the benchmarked algorithm.

MinPercent	LenPercent	Ratio	P0	Sample
0.005	0.4	0.85	0.4	10

Table 2. The solution quality for both algorithms.

Test	Numbers of	Average cost ($)		Best available
Problem no.	Machines and Cells	Proposed algorithm (%)	Benchmark algorithm (%)	
1	M=6 and C=2	82.00 (0.00)	82.10 (0.12)	82
2	M=12 and C=4	943.61 (0.06)	944.16 (0.12)	943
3	M=20 and C=5	3870.00 (0.00)	3870.00 (0.00)	3870
4	M=30 and C=6	10689.90 (0.21)	10701.40 (0.32)	10667
5	M=50 and C=8	29722.24 (0.04)	29729.30 (0.07)	29709
6	M=100 and C=12	158211.20 (0.05)	158222.00 (0.05)	158139
7	M=150 and C=14	1368600.00 (0.03)	1369084.90 (0.06)	1368249
8	M=200 and C=21	2589018.60 (0.07)	2590929.40 (0.14)	2587318
9	M=250 and C=28	5091747.4 (0.02)	5097374.33 (0.13)	5090508

time. In the following the mechanism of each algorithm will be explained.

Mechanism of the proposed algorithm

The proposed algorithm based on material flow calculates the material flow of each machine with other machine cells and the material flow between each two machine cell. Based on the material flow of machine cells, it finds the arrangement of cells. Then, the algorithm determines the arrangement of machines with considering the material flow of all machines that are existed in the shop floor. In the following, the parameters set, which is used for the proposed SA algorithm is shown in Table 1.

Mechanism of the benchmarked algorithm

In the benchmarked algorithm in order to generate an alternative layout, two machines are selected randomly. If the selected machines belong to the same machine cell, the algorithm will swap the location of those machines; otherwise, the algorithm changes the location of the machine cells which those machines belong to. The tuned value of the parameter set, which is used in the benchmarked algorithm, is shown in Table 2.

Solution quality and execution time

Both algorithms are run on a PC 2.8 GHZ Pentium 4 with 1 GB RAM and because of the stochastic nature of SA, each algorithm is run ten times for each test problem. The results of these two algorithms are compared in terms of average of material handling cost and average of computation time. In order to compare the solutions in terms of solution quality, the best available solutions (minimum material handling cost) were found during the ten times running of each algorithm for each of the test problems. The results are summarized in Table 3 and Table 4.

Comparison of results in terms of solution quality in Figure 1 shows that the proposed algorithm and the benchmarked algorithm from the literature produce results, which are nearly as good as the best available solution, but comparing the computation time in Figure 2,

Table 3. Computation time for both algorithms.

Test	Numbers of	CPU time (Sec)	
Problem no.	Machines and Cells	Proposed algorithm	Benchmark algorithm
1	M=6 and C=2	0.001	0.047
2	M=12 and C=4	0.007	0.36
3	M=20 and C=5	0.041	0.66
4	M=30 and C=6	0.168	7.1
5	M=50 and C=8	1.12	23.81
6	M=100 and C=12	17.6	208.7
7	M=150 and C=14	91.7	326.9
8	M=200 and C=21	265.9	834.8
9	M=250 and C=28	568.1	1391.7

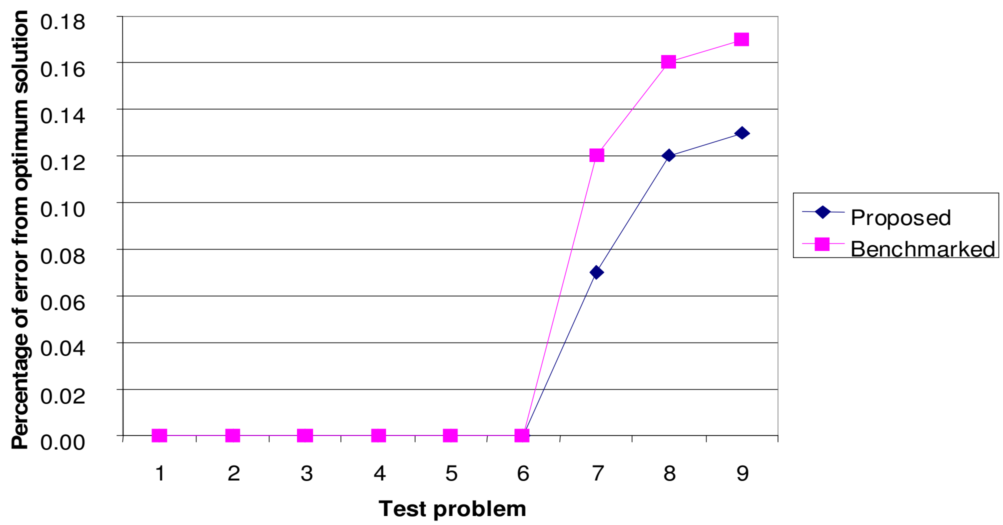

Figure 1. Comparison of algorithms based on solution quality.

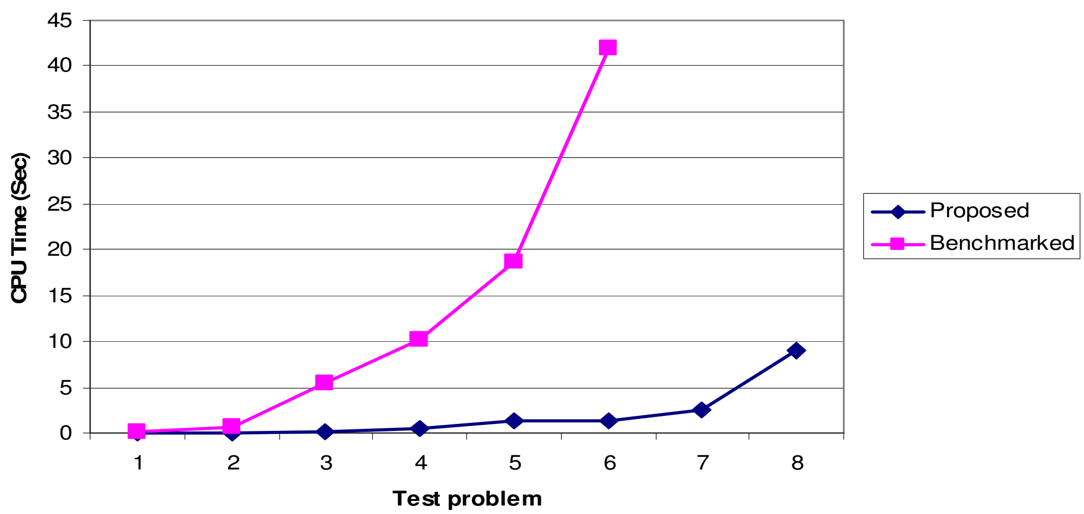

Figure 2. Comparison of algorithms based on CPU time.

shows that the computational time of the proposed algorithm is significantly less than the benchmarked algorithm.

Conclusion

This paper examined the issue of layout problem in hybrid manufacturing systems which is composed of some regular cells and special reminder cells for exceptional parts. A new mathematical model for layout problem in hybrid manufacturing system was proposed and a variant of simulated annealing algorithm was developed to solve the problem. Comparison of the results between the proposed algorithm and benchmarked algorithm from the literature showed that although both algorithms produce nearly the same quality solutions with maximally 0.32% error in the benchmarked algorithm, the developed SA algorithm is more effective, since the time taking to find the solution is comparatively reasonable.

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