Paper ID: NITETMECH09

INTEGRATIVE CELL FORMATION IN CELLULAR MANUFACTURING SYSTEMS

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ABSTRACT
In this paper a new integrative view of manufacturing cell formation and both inter-cell and intra-cell layout problems are discussed. Cells formation are determined simultaneously through a Dynamic Programming algorithm with the objective of minimizing the inter-cell flow cost. This Dynamic Programming algorithm is implemented in a Simulated Annealing approach with Genetic operators to reach near optimal solutions. Moreover, within this approach by using an Ant Colony optimization technique, They also solve the intra-cell layout problem, i.e., they also determine how to layout machines within relative cells.(1) An integrated objective function to minimize overall inter-cell and intra-cell flow costs instead of merely minimizing the number of inter-cell movements/costs. (2) The integrative and simultaneous determination of cell formation and their layout instead of using sequential approaches. (3) All three phases of cell formation, inter cell and intra-cell layout design problems, which are all important for overall performance of the system, and (4) An easy to code and solve integrated procedure through implementing meta heuristic approaches. Their computational results show that by incorporating intra-cell decisions in cell formation and inter-cell design process through implementing their proposed integrated approach, a manufacturer can largely reduce their total material flow cost. Particularly our computational tests give good quality solutions in comparison with the most similar available approach in the literature with an average improvement of 24.97% in total flow cost for a set of randomly generated test problems.

KEYWORDS: Cell Formation, Intra-cell Layout, Inter-cell Layout, Simulated Annealing, Dynamic Programming, Ant Colony Optimization.

INTRODUCTION

The concept of GT was originally proposed by Mitrofanov (1966) and Burbidge (1975). Mitrofanov (1966) defined GT as a method of manufacturing piece parts by the classification of these parts into group and subsequently applying to each group similar technological operations. The most general definition of GT defines it as a manufacturing philosophy which identifies and exploits the underlying proximity of parts and manufacturing processes. A cell can defined as a group of closely located work stations where multiple sequential operations are performed on one or more families of similar raw materials, parts, components, products or information carries. They define a manufacturing cell as a cell whose main purpose is to physically process, transform, transmit and add value to materials whose end state are products or components .A manufacturing cell as an independent group of functionally dissimilar machines, located together on the floor, dedicated to the manufacturer of a family of similar parts. A Cellular Manufacturing System (CMS) design is usually partitioned to several phases, including the selection of parts and part families, machines and machine cells, tools and fixtures, material handling facilities and layout (Wemmerlov and Hyer (1987)). Obviously, these phases are not independent and should all be considered through cell design goals. The overall goal for the design process is to achieve performance improvement with respect to lead time, inventory, quality or other measures or in other words, to achieve advantages of a CMS.

The most important advantage of CMS are include reduction in move times, throughput and lead time, WIP and finished goods inventory levels, setup times, as well as improvement in quality, capacity and equipment utilization. There are many available studies in the field of CMS design. Most of them, however, are focused on the cell formation problem. Moreover, there are not so many papers that concurrently consider all three phases of the design, namely part/machines grouping, intra-cell and inter-cell layout designs within an integrated approach. Formation technique is that they do not lay out machines in cells (intra-cell layout) and on the shop floor (inter-cell layouts). There are also a few approaches for the layout problem in CM Moreover, most of the available studies for the cell formation problem are concerned with creating machine cells with minimal number of inter-cell movements and not with minimal flow cost cell formation with minimal number of inter-cell movements is not always consistent with the one with minimal inter-cell material flow cost, due to lack of layout data in the cell formation process. Additionally, although the cell formation and the inter-cell layout problems have been jointly considered in the literature, most of the available methods are either based on the sequential approaches in which machine cells are found in first phase and then inter-cell layout is constructed based on the given cell formation; thus the quality of final solution largely depends on the given cell formation or are based on difficult mathematical models (in which solving the problem is not easy,

In this paper, by improving and combining the studies of Lee and Chiang (2001), Chiang and Lee (2004), we propose an integrative and easy to code approach which integrates all three phases of a CMS design: cell formation, its location sequence on the bidirectional linear flow layout and the intra-cell machine layouts. We modify their approach to be able to implement it for our intra-cell (and not inter-cell) layout decision making as a part of our integrated approach. We consider this criterion as the objective function. Moreover, we notice that all these design decisions are correlated in the sense that they affect each other. Hence, we propose an integrative and simultaneous consideration of different design decisions instead of available sequential approaches. Our computational results, as will be discussed, show that by incorporating intra-cell decisions in cell formation and inter-cell design process, and through implementing our proposed integrated approach, a manufacturer can largely reduce their total material flow cost.

ASSUMPTIONS AND SA PROCEDURE

1) Our objective is to minimize total cost of inter-cell and intra-cell flows subject to a cell size constraint, i.e., the maximum number of machines allowed in each cell. We consider a center-to center linear distance measure and for simplification, we do not consider any other spatial constraint. However, one may note that such constraints can also be added to the model by some simple modifications to the will-be proposed procedure.

2) As the problem of partitioning a manufacturing system into several subsystems, with the objective of minimizing inter-cell flow movement cost is NP-complete (Garey and Johnson (1979)), most researchers have focused on developing heuristics or met heuristics. In this paper, as well, we propose an enhanced Simulated Annealing (SA) in which the crossover and mutation operators of Genetic Algorithm (GA) are used as generation mechanism to generate neighborhood solution.

3) For a physical annealing process of condensed matter gave a comprehensive discussion of the theory and review of various applications.

The main procedure of SA can be described as follows. It starts from an initial solution to the problem, and then generates a new trial solution from the neighborhood at the current solution. If the new solution is better than the current solution it is accepted and used as the new current solution. Otherwise, it may be accepted or rejected depending on an acceptance probability, which is determined by the difference between objective function of the two solutions and by a control parameter called temperature, following the convention in thermodynamics. This process then continues from the new current solution. Initially, the temperature is set at high level, as in annealing, so that almost all moves will be accepted. It is then decreased slowly during the procedure until almost no move will be accepted. In other words,

SA PROCEDURE CAN BE GENERALLY DESCRIBED AS FOLLOWING STEPS.

1. Initialization: set parameters of annealing schedule.
2. Select an iteration mechanism: a simple prescription to generate a transition from current state to another state by a small perturbation.
3. Evaluate the new state and compute□E □ (value of current state - value of new state) .

4. If the new state is better, make it current state, otherwise probabilistically accept or reject it (with a determined probability function usually called acceptance probability function).
5. Based on stopping rules either stop or continue iterations at step 2. A simulated annealing algorithm works with a coding of solution configuration. In this study, the configuration of solution, as is common, consists of a string of integer values. Each integer value is the code for one machine and the order of machines in the string is associated with the sequence of machines at the incidence matrix. For instance, the symbolic string □ =(8, 1, 3, 5, 4, 2, 7, 6), represents the sequence of eight machines appearing in the row of the incidence matrix. If a cell formation problem involves m machines, a string with the defining length of m is needed to encode the candidate solution. This string then will be segmented and each segment represents a machine cell. A Dynamic Programming approach that uses the idea of a graph of material flow is then used to determine the best cell formation, location sequence and inter-cell flow cost of that cell formation regarding the best layout. Consequently, the number of cells, despite of sequential procedures, is obtained through the optimal policy and is not determined before layout design. After such determination and during our integrative procedure, we will deal with intra-cell layout, i.e., to layout machines in each cell. This will be done by modeling the problem as a famous Quadratic Assignment Problem (QAP) model and developing an Ant Colony Optimization (ACO) technique

INTEGRATED SOLUTION PROCEDURE

As mentioned previously, we implement a Simulated Annealing approach that uses crossover and mutation operators. Additionally, as will be described in details, a Dynamic Programming procedure and an Ant Colony Optimization (ACO) technique are embedded. The major reasons for implementing this approach include: (a) Our skills and experiences in implementing SA and ACO, and (b) Effective results, achieved by previous researchers.
To describe the procedure in more details, notice that the sequence of machines needs to be partitioned into a number of segments under the cell size constraint. To this end, a Dynamic Programming algorithm is developed to achieve minimum TC , i.e., the minimum inter-cell total flow cost. Each partition then will be treated as a cell. Moreover, TC□ (i.e., the intra-cell total flow cost) will be added to TC to build up the total material handling cost. TC□ will be determined by an Ant Colony Optimization (ACO) technique, used to solve the QAP model in each stage of our SA procedure. Our main integrated approach is as follows.

Step 1. Construct a set of initial solutions (parent solution). Each solution is generated randomly by assigning m machines into a sequence.

Step 2. Define the initial temperature T and parameters such as the length of equilibrium, the
Cooling rate of temperature, and the population size.

Step 3. While not yet frozen do:

Step 3.1. While not yet equilibrium do
Compute the inter-cell and then according to that the intra-cell flow cost (TC &TC□ (parent)) of
each parent solution in the current set respectively by the Dynamic Programming algorithm and the Ant Colony technique for the QAP model.
Generate a set of neighborhood (child) solution via the crossover and mutation operators in the
genetic algorithm.
Compute the inter-cell and then according to that the intra-cell flow cost (TC & TC□ (child)) of
each child solution set respectively by the Dynamic Programming algorithm and the Ant Colony
technique for the QAP model.
For each pair of solutions in the parent set and the child set do:
Calculate the cost improvement □ = (TC(child) - TC(parent))+(TC□ (child)- TC□ (parent)).
If □ □ 0 , the solution in the parent set is replaced by the one in the child set.
Otherwise, the solution will be replaced by an acceptance probability exp(□ □/T).

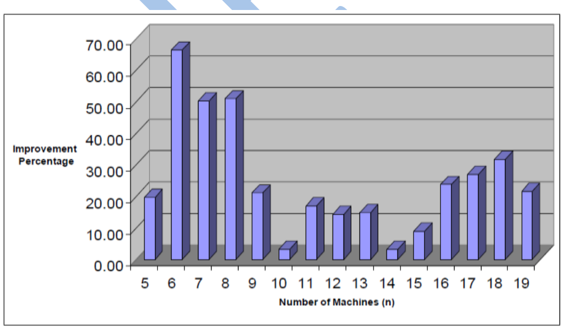
Step 3.2. Reduce the current temperature through a fixed cooling ratio.

Step 3.3. End of while

Step 4. The algorithm is terminated when either (1) the best solution and the worst solution in the population set are equal, or (2) the temperature has been reduced below the user-defined value. The best solution in the current population set at the frozen temperature is treated as the optimal solution.
to step 4.

COMPUTATIONA L RESULTS

To illustrate the efficiency of our proposed integrated procedure, we have implemented our algorithm to solve 15 randomly generated test problems. We have compared the results of our approach with the previous available one in the literature, i.e., the proposed approach of Chiang and Lee (2004). We use "C&L" (Chiang and Lee) to refer to their approach and "S&A" (Shaiesh & Athani) to refer to our proposed procedure. We consider the criterion of total material flow cost and compare these two approaches. It is noteworthy that in both approaches intra-cell flow costs can be computed based on the objective function of the described QAP model; where this objective is heuristically optimized in "A&P" but this is not the case for "C&L". In order to maximize the similarity of our test problems with what "C&L" implemented as their test suites, we have used same data to generate our 15 randomly generated test suites. We also have coded both approaches and implemented them with same input data on a same platform. Table 1 shows the dimension of test problems as well as obtained results. Moreover, Table 1 also presents the resulting solution of each procedure. In this table we denote the cell boundaries by "/". Hence, the sequence of machines in each cell (from left to right) shows the intra-cell layout of that cell according to the QAP model. For instance "1 2/ 3 4" describes that there are two cells in the layout: machine 1 and 2 form the first cell, and machines 3 and 4 form the second one. Machine 1 is placed in the first available place of the first cell, and machine 2 in the second place of this cell. Also, machines 3 and 4 are placed in the first and second available places of cell 2, respectively. The results presented in Table 1 reveal that our proposed approach achieves solutions with lower total cell flow cost for all implemented test problems. This is mainly due to the fact that our approach is more integrated than the previous available one in the literature. In other words, it considers cell formation, intra-cell material, and inter-cell flows in a jointly manner. The average percent of improvement in total cost is 24.97% with the best improvement of 66.41% for n=6 and the worse of 3.32% for n=10. Figure 1 illustrates the percentage of improvement in total cost for different number of machines. Figure 2 depicts the comparison of our proposed algorithm (A&P) with that of Chiang and Lee (C&L) based on the total flow cost. One can observe that as 'n' increases, the difference between resulted total flow costs grows approximately in an exponential way.
Moreover, Figure 3 compares two approaches by considering the resulted inter-cell flow costs. Although our procedure and that of Chiang and Lee (2004) are approximately similar in dealing with the inter-cell layout design, one can observe a slight difference and that is related to the random nature of both algorithms. However, since our proposed procedure modifies a strong Ant Colony Optimization (ACO) technique to also incorporate the intra-cell layout problem, a major difference happens regarding this important component of total flow cost. This difference highlights the importance of considering intra-cell decisions in cell formation and inter-cell layout problems with respect to total material flow costs. Figure 4 demonstrates this statement by comparing two procedures based on their intra-cell flow costs.



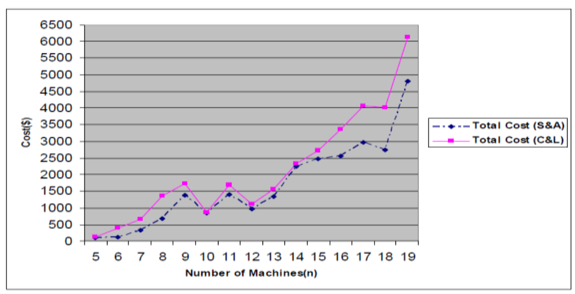


Figure 2 comparison of (A&P) with old (C&L)

Figure 1 Improvement percentage in total flow cost

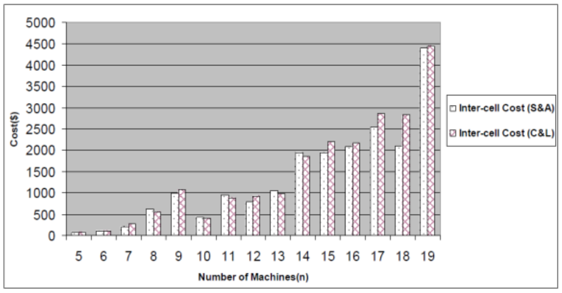


Figure 3 Comparison of two procedures by total inter-cell flow costs.

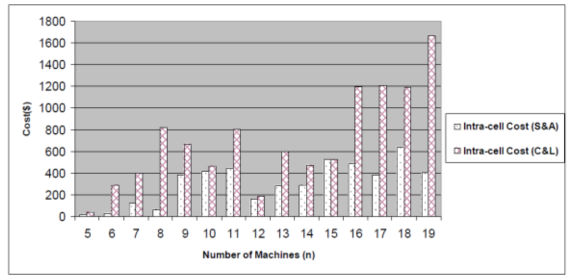


Figure 4 Comparison of two procedures with total intra-cell flow costs.

CONCLUSION

In this paper, we proposed an integrative view for all three phases of cellular manufacturing systems design, i.e., cell formation, inter and intra-cell layout design. The main algorithm was a Simulated Annealing approach in which a Dynamic Programming (based on the graph representation of material flow) and an Ant Colony algorithm (based on a QAP model) were implemented, respectively for inter-cell and intra-cell layout decisions. Table 1 Computational results with dimensions of random generated test problems.

Table 1 Computational results with dimensions of random generated test problems

Problem No.	n	Q	Resulting Solution (S&A)	Resulting Solution (C&L)	Inter-cell Cost (S&A)	Inter- cell Cost (C&L)	Intra-cell Cost (S&A)	Intra-cell Cost (C&L)	Total Cost(S&A)	Total Cost(C&L)	Cost Improvement Percentage
1	5	3	3 2 /5 4 1	2 3/5 1 4	80	80	18	42	98	122	19.67
2	6	3	6 2 3 / 1 4 5	2 6 3/ 4 1 5	100	100	31	290	131	390	66.41
3	7	3	7 3 2 /6/ 4 1 5	6 2 3/ 7/ 4 1 5	208	264	120	396	328	660	50.30
4	8	3	6 2 3 / 5 7 8 / 1 4	6 2 3 / 7 8 / 4 5 1	612	550	60	821	672	1371	50.98
5	9	4	1 5 2 8 / 6 7 3 4 / 9	8 / 6 5 1 2 / 7 4 9 3	988	1074	384	668	1374	1742	21.13
6	10	5	7 / 2 9 5 6 3 / 4 10 1 8	2 7 3 9 5 / 8 10 4 6 1	428	405	416	468	844	873	3.32
7	11	5	7 / 6 / 2 5 3 11 9 / 10 1 8 4	3 / 5 2 11 7 9 / 1 8 10 6 4	950	881	446	801	1396	1682	17.00
8	12	5	13 / 2 3 7 9 11 / 1 5/ 10 6 8 4	11 / 3 / 1 / 9 5 2 7 / 8 4 10 6 12	798	935	162	186	960	1121	14.36
9	13	5	11/ 5 7 1 2 9 / 3/ 12 4 13 / 10 6 8	9/ 2 3 13 7 5 / 6 / 10 8 11 4 12	1050	968	282	597	1332	1565	14.89
10	14	5	5 9 2 7 / 12 11 / 3/ 4 6 14 / 8 1 10 13	2/ 9/ 5 7 11 14 / 8 / 10 3 / 13 1 4 6 12	1953	1850	292	472	2245	2322	3.32
11	15	5	5 / 4 14 / 7 / 8 2 3 15 9 / 10 / 6 11 1 13 12	9 / 8 / 10 / 3 5 15 4 14 / 13 7 2 12 11 / 6 1	1950	2197	525	524	2475	2721	9.04
12	16	6	10/ 4 3 5 14 16 / 9 11 15 /1/ 2 13 6 7 12 8	2 3 4 5 14 16 / 11 9 15 / 10/ 1 6 13 7 8 12	2078	2174	490	1198	2568	3372	23.84
13	17	6	5/ 3 15 16 / 9 11/ 4 / 8 14/ 1 10 2 13 12 7/ 6 17	8 /4 14 16 10 3 5/ 9 11 15 17 6/ 12 1 13 7 2	2540	2857	380	1207	2970	4065	26.94
14	18	6	3 14 4 5 18 16 / 12 13 / 8 7 2 15 / 9 1 6 17 10 11	9 11 /15 /3 5 4 16 18 14 /7 8 /10 2 13 1 12/ 6	2103	2827	640	1190	2743	4017	31.72
15	19	6	17 8 / 11 9 / 12 3 16 13 / 19 14 5 6 / 15 4 7 18 1 2 / 10	5 /3 / 8 4 15 9 17 11 / 16 18 /16 18 / 1 12 14 6 19 3 /7 10 2	4396	4451	404	1670	4800	6121	21.58

REFERENCES

[1] Askin R., Subramanian S. (1987), A cost-based heuristic for group technology configuration; International Journal of Production Research 25(1); 101–113.
[2] Bazargan-Lari M., Kaebernick H., Harraf A. (2000), Cell formation and layout design in a cellular manufacturing environment-a case study; International Journal of Production Research 38(7); 1689- 1709.
[3] Burbidge J.L. (1975), The Introduction of Group Technology; Wiley, New York.
[4] Chen W-H, Srivastava B. (1994), Simulated annealing procedures for forming machine cells in group technology; European Journal of Operational Research 75; 100–11.
[5] Chiang C.-P., Lee S.-D. (2004), Joint determination of machine cells and linear intercell layout; Computer and Operations Research 31(10); 1603-1619.
[6] Colorni A., Dorigo M., Maniezzo V., Trubian M. (1994), Ant system for job-shop scheduling. JORBEL; Belgian Journal of Operations Research Statistics and Computer Science 34 (1); 39–53.
[7] Dorigo M., Gambardella L.M. (1997), Ant colony system: a cooperative learning approach to the traveling salesman problem; IEEE Transactions on Evolutionary Computation (1); 53–66.