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GENETIC ALGORITHM FOR RESTRICTED AREAS LAYOUT PROBLEMS IN CELLULAR MANUFACTURING SYSTEMS

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Abstract: The layout does affect the operational performance of manufacturing cells in a Cellular Manufacturing System (CMS), this issue has widely attracted attention of researchers for intercellular and intracellular layout problem but there are a limited research addressing the aspects of restricted areas layout in CMS. The gist of literature is discussed in literature survey. Proper layout of manufacturing cells is a crucial factor in obtaining the desired effectiveness of CMS. Basically, any solution for the layout of CMS has to address two main issues: (a) location of manufacturing cells, (b) layout of machines within the cells. These two problems are referred as intercellular and intracellular layout problems, respectively. A comprehensive genetic algorithm based solution methodology is proposed for solving these layout problems in CMS. This paper discusses the intercellular layout problem initially. The mathematical formulation of the model and proposed genetic algorithm methodology are discussed. This methodology is extended for restricted areas problems layout problems. The computational results are given for some of the restricted areas layout problems. The issues are discussed in the conclusion.

***Index Terms* – Cellular manufacturing system, Genetic algorithm, Intercellular layout, restricted areas layout.**

I. INTRODUCTION

Most of the cell formation studies have focused on the independence of cells, and the number of inter cell movements is commonly viewed as an indicator of independence. In addition, various objectives, such as maximizing utilization of machines, minimizing material handling cost, and minimizing load unbalance, have been employed in assessing the quality of the cell formation. A zero-one binary incidence matrix offers advantages of computational simplicity for solving the cell formation problem. However, it is not possible to address issues pertaining to machine utilization, intercell workload, impact of multiple copies of machines and layout of machines within each identified cell. Use of additional data such as setup time, process time, production volume, sequence of operations address these issue but require a more complex solution methodology. It is almost impractical to achieve an ideal configuration of manufacturing cells with no intercellular moves. This is due to the fact that duplication of bottleneck machines may not be economically justifiable or physically possible and subcontracting of exceptional parts may not be cost-effective as well.

On the other hand, layout of manufacturing cells affects the total material handling distance/cost. Thus, manufacturing cells are to be laid in such a manner that the total material handling distance/cost induced due to intercellular moves is minimal. This problem has been referred as intercell layout problem. The intercell layout problem deals with arrangement of n machine cells at n possible locations so that the expected movement of the material handling systems among the cells is minimized. It is assumed that the locations are predefined and therefore the distance matrix, $D=[D_{jl}]$, $\forall j,l\ (=1,2,\ldots,n)$ is known in which D_{jl} represents the distance between locations j and l.

An important issue in the intercell layout problem is to determine the frequency of trips between each pair of cells i and k. This is represented by a flow matrix, $F=[F_{ik}]$, $\forall j,l\ (=1,2,\ldots,n)$ which represents the number of trips between cell i and cell k in a given time horizon. In intercell layout problem in CMS, the measure F_{ik} represents the total number of intercellular moves and therefore it mainly depends upon the quality of the solution obtained from the cell formation problem. The sequence of operations is taken from route sheet of parts and production volumes are obtained from production plan considering the limitation of capacity of machines. As an illustration, Table 1 gives the operation sequences of nine parts and these are processed by a total of eight machines (Solimanpur, 2004). In the Table 1, machine-part cell matrix obtained from operation sequences of eight parts processed on total of nine machines with their respective production volumes are provided. This entry shows the sequence in which the related part visits the corresponding machine. The last row in the figure shows the production volumes of parts with four part families.

Table 1: Operation sequence and production volume

Type of parts	Operation sequence- parts	Quantity
1	M6	82
2	M3→M1→M8	80
3	M4→M6→M8→M3	90
4	M9→M5→M7	70
5	M3→M1→M4	75
6	M5→M7	68
7	M1→M4→M3	60
8	M9→M5→M2→M6	100

Table 2: Cell formation of 9-machine and 8-part

Cell	P2	P3	P5	P7	P8	P1	P4	P6
M3	1	4	1					
M8	3	3						
M1	2		2	1				
M4		1	3	2				
M6		2			4	1		
M2				3	3			
M5					2		2	1
M9					1		1	
M7							3	2
Vol.	80	90	75	60	100	82	70	68

Table 3: Intercell flow matrix

	Cell 1	Cell 2	Cell 3	Cell 4
Cell 1	0	155	0	0
Cell 2	80	0	150	0
Cell 3	90	0	0	0
Cell 4	0	0	100	0

Four machine cells are formed by cell formation. The cells obtained are C_1= (M_3, M_3), (P_2, P_3), C_2= (M_1, M_4), (P_5, P_7), C3= (M_2, M_6), (P_1, P_8), and C_4= (M_5, M_7, M_9), (P_4, P_6). The numbers of trips are calculated and the intercell flow matrix is given in Table 3. The material flows from cell 1 to cell 2, f_{12}= 155 are calculated as follows: first operation of part 2 is done in cell 1 and then it goes to cell 2 to get processed on machine 1. This transfer creates 80 flows of parts from cell 1 to cell 2. Similarly, part 5 is processed on machine 3 in cell 1; therefore 75 flows are created due to part 5. Hence, total flows from cell 1 to cell 2 is calculated as f_{12} = 80+75 = 155. Similarly, other flows are calculated.

II. LITERATURE SURVEY AND MATHEMATICAL MODELLING

Heragu and Kusiak (1988) focused on the machine layout problem. They classified machine layouts into four categories. A set of heuristic rules was used to arrange machines in several equally sized sites. Heragu (1989) developed a three-stage methodology for the layout problem in CMS. The first stage relates to the grouping of machines. The intercell and intracell layout problems are formulated as mathematical programming models in the second and third stages, respectively. A knowledge-based system is discussed to integrate these stages. This attempted a model integrating cell formation and facility layout problems in cellular manufacturing systems. In this model, it is assumed that the locations of cells are known a priori. Their formulated model considers only the layout of machines within the manufacturing cells. Heragu and Gupta (1994) developed a heuristic which considers machine capacity, safety, technological requirements, upper limit on cell size and number of cells. By supplying various values of parameters, users can generate a number of solutions and select the most acceptable. Bazargan-Lari (1999) has explored the application of multi-objective intercell and intracell layout design methodologies in a cellular manufacturing environment. Nonlinear goal programming and simulated annealing approaches have been used to solve this problem. Several intercell layout configurations are generated out of which a suitable design can be selected. Bazargan-Lari et al. (2000) integrated all three stages required in the design of CMS, i.e. machine-component grouping, intercell layout of manufacturing cells, and the layout of machines inside the cells. Constraints such as non overlapping conditions, shop floor boundaries, closeness relationships, location preferences, machine orientations and traveling costs are considered for both intracell and intercell layout problems. A heuristic is used to solve problem. The approach is applied to real case in Australia. Sarker and Xu (2000) considered an operation sequence based method, which integrates intracell layout and cell formation problems in order to minimize total cost of materials flow and machine investment. The approach consists of three phases. In the first phase, an operation sequence based similarity coefficient is applied in a p-median model to form part families. In the second phase, machines are assigned into part families. In the third phase, the intracell layout of each cell is determined in order to minimize the intracell backtracking flow cost in each cell. Urban et al. (2000) proposed a model in which the material flow requirements dictate the layout of machines. The model is an aggregation of the quadratic assignment problem and several network flow problems coupled with linear side constraints. A mixed integer program has been proposed to optimally solve small problems. Heuristics are developed for larger problems. Wang and Sarker (2002) considered the intercell layout problem in cellular manufacturing in which machine cells are assigned into different locations so that the total intercell material handling cost is minimized. The intercell layout problem is formulated as a quadratic assignment problem and a 3-pair comparison heuristic is developed to solve this problem. The solution constructed by 3-pair comparison heuristic is further optimized through an improvement heuristic called ‘bubble search’. One dimensional equidistant problem, considering sequence of operation and equidistant location was formulated as QAP. Solimanpur et al. (2004) proposed ant colony optimization algorithm to solve the problem which is formulated as QAP. The performance of algorithm is compared with other heuristics. The results show that algorithm is effective and efficient for intercell layout problem. Adel El-Baz (2004) described a genetic algorithm to solve problem of optimal facilities layout in manufacturing systems design so that material handling costs are minimized. Various material flow patterns are considered. The effectiveness of GA approach is evaluated with numerical examples. The cost performances are compared with other approaches. Chan et al. (2006) developed a two stage approach for machine-part grouping and cell layout problems. The first stage is to identify machine cells and part families. In the second stage, layout considerations are dealt with QAP. Genetic Algorithm methodology is employed as solving algorithm. Wu et al. (2006) developed a genetic algorithm to address CMS design and layout simultaneously. The algorithm includes a hierarchical chromosome structure to encode both decisions. The proposed structure and operators are found effective for improving solution quality. A heuristic is presented to find initial solution for the problem and GA is applied to improve the quality of the solution. The quadratic assignment problems have been widely used for facility layout problems. Let us consider the problem of assigning facilities to locations in such a way that each facility is designated to exactly one location and vice-versa. The distances between locations, the demand flows among the facilities are known. The problem of finding a minimum cost allocation of facilities into locations is identified as quadratic assignment problem (QAP). Since then QAP is one of the most sought problem by number of researches in combinatorial optimization. Various formulations, bounds and relaxations are present. The different methods to achieve a global optimum for QAP include branch-and-bound, cutting planes and combinations of them. There are number of heuristic techniques using different concepts. Heuristic algorithms do not give a guarantee of optimality for the best solution obtained. Heuristic procedures include constructive, limited enumeration and improvement methods. The intercell layout problem can be formulated as a QAP. Consider a problem of locating n cells in n given locations. Each location can be assigned to only one cell, and each cell can be assigned to only one location. There is material handling flow between the different cells and a cost associated with the unit material handling flow per distance. Thus, different layouts can have different total material handling costs depending on the relative location of the cells. If F_{ik} is the flow between cell i and cell k, and D_{jl} is the distance between two locations j and l. The mathematical programming formulation for the problem is given below.

The following notations are used for the development of mathematical model.

$i = 1, 2, ..., n$	Cells
$k = 1, 2, ..., n$	Cells
$j = 1, 2, ..., n$	Locations

$l = 1, 2, ..., k$ Locations

F_{ik} = Flow between cell i and cell k

D_{jl} = Distance between location j and location l

$$X_{ij} = \begin{cases} 1, \text{if cell } i \text{ is assigned to location } j \\ 0, \text{Otherwise} \end{cases}$$

Model formulation of QAP

Objective Function: Minimization of sum of flow over every pair of cell

$$\text{Min } Flow = \sum_{\substack{i=1 \\ i \neq k}}^{n} \sum_{\substack{j=1 \\ j \neq l}}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} F_{ik} \times D_{jl} \times X_{ij} \times X_{kl} \qquad (1)$$

Constraints:

(1) Ensures that each location contains only one cell

$$\sum_{j=1}^{n} X_{ij} = 1, \qquad \forall i = 1, 2, \ldots, n. \qquad (2)$$

(2) Ensures that each cell get only one location

$$\sum_{i=1}^{n} X_{ij} = 1, \qquad \forall j = 1, 2, \ldots, n. \qquad (3)$$

To illustrate the QAP, the above example is considered. Now, four cells 1, 2, 3, 4 are to be arranged in four locations A, B, C and D in a rectangular matrix form. Therefore, we get the flow matrix F_{ik} from the route card and the production volume from the production planning. To calculate the distance matrix, the distances between the cells are assumed to be same. The distances between the cells are Manhattan distance shown in the Table 4. There will be three combinations of layout and the flows are 910, 725 and 665. Since minimal flow cost is 665, best values provided assignments are shown in Table 5.

Table 4: Distance matrix

	Cell 1	Cell 2	Cell 3	Cell 4
Cell 1	0	1	1	2
Cell 2	1	0	2	1
Cell 3	1	2	0	1
Cell 4	2	1	1	0

Table 5: Result

1-C	2-D
3-B	4-A

QAP is a NP-hard optimization problem and one of the hardest problems that is almost impossible to be optimally solved in an acceptable time for more than thirty facilities/cells. Therefore, several heuristics such as Simulated Annealing, Genetic Algorithm, Tabu search, Ant colony etc. have been developed by researchers to provide near optimal solutions for QAP. Various ideas for the use of genetic algorithms on the QAP can be found in the literature. Adel El-baz (2004) applied it for different types of manufacturing environments. Genetic algorithm (GA) is used to deal with intercell layout problem.

III. GENETIC ALGORITHM METHODOLOGY

The detailed information genetic algorithm is available in literature. Genetic algorithm has been proposed as an innovative approach to solve the CMS layout problem. In this paper, a genetic algorithm is proposed that generates only feasible strings after crossover and mutation. New crossover scheme and mutation scheme are proposed. The new crossover operator is employed that always generating feasible child during crossover and hence checking of the feasibility of child is not required. The proposed crossover scheme is named as circular crossover. A swapped mutation scheme is developed to mutate the pool of selected parents. The proposed genetic search based approach along with the circular crossover and swapped mutation operator is described below. Binary tournament selection is employed which is described in detail in chapter three. In the following section, the chromosome structure, circular crossover scheme, swapped mutation scheme, and stopping criteria are discussed.

IV. CHROMOSOME REPRESENTATION

The genetic algorithm requires a chromosome representation scheme as in Figure 1. The entire manufacturing plant/ department are divided into rectangular grids and each grid represents a machine location. For example, here two types of production plant layouts are considered. Suppose in case of a process shop layout, there are 9 machines whose locations are identified by location number as shown in the Figure 1(a). The chromosome structure will have 9 genes. The gene contains the cell number to which the location is assigned accordingly. As shown in the chromosome structure, machine 5 will be located at location number 1 and machine 3 will be located at location 4. Similarly, in case of line layout with single line, the location numbers are given in the direction of flow. For illustration in the Figure 1(b), 5 locations line layout is considered. In this case, in the chromosome structure, machine 3 will be located at location number 1 followed by machine 2 will be located at location number 2. It is to be noted that this representation automatically satisfies the constraints (2) and (3) in the formulation. Thus, for both the types considered, the chromosome structure will be same. The number of alleles in the chromosome will be equal to the number of machine locations available.

1	2	3
4	5	6
7	8	9

(a) Process shop layout Chromosome structure of process shop

5	1	9	3	4	6	8	7	2

Flow →

1	2	3	4	5

(b) Line layout- single Chromosome structure of line layout

3	2	4	5	1

Figure 1: Types of layout and chromosomes representation

V. CIRCULAR CROSS OVER SCHEME

The probability of crossover is the probability of applying the crossover to the selected chromosomes. The crossover scheme of genetic algorithm is designed to generate feasible child on crossover. Single point crossover is applied to a single parent. The methodology of the circular crossover scheme can best be viewed from the Figure 2 for 9 cells/location case. In this case, two parents are shown for simplicity. A random number between 1 to number of locations is sought. Suppose the cross over site 7^{th} is selected at location randomly. By this the chromosome will have two sections. The child 1 formed from parent 1 will begin with the alleles from 8^{th} position of the second section up to the end of chromosome structure and then followed by 1^{st} allele up to end of first section. Similarly, in case of parent 2, the chromosome will have the second section followed by the first section.

Crossover point 7^{th} location ↓

Parent 1	8	9	3	1	6	5	2	4	7
Parent 2	3	5	1	4	2	6	8	7	9
				After Crossover					
Child 1	4	7	8	9	3	1	6	5	2
Child 2	7	9	3	5	1	4	2	6	8

Figure 2: Single point crossover scheme

VI. .SWAPPED MUTATION SCHEME

In swapped mutation scheme, the alleles of chromosome are exchanged with their locations. The swapped mutation scheme exchange scheme, two random numbers between 1 and number of locations are sought. The schematic diagram of mutation methodology is shown in Figure 3.

3^{rd} location ↓ 7^{th} location ↓

Parent	8	9	3	1	6	5	2	4	7
				After Mutation					
Child	8	9	2	1	6	5	3	4	7

Figure 3: Swapped mutation scheme

For illustration, the two random numbers are assumed to be 3 and 7. Then the alleles in the chromosome at these locations are swapped. The proposed swapped mutation scheme is carried on a single parent selected and child is obtained. The swapped mutation scheme is simple for implementation. It avoids the problem of infeasibility. The best chromosomes are retained in the population by evaluating their fitness values. The newly formed population is ready for next generation until maximum generations are reached.

VII. PROBLEM SOLVING, RESULTS AND DISCUSSION

The scheme of the experimentation is to compare the performance of the proposed Genetic algorithm with other applications of genetic algorithm recently proposed for QAP for solving problems in intercell layout in cellular manufacturing, which is described below. The effectiveness of the proposed approach can be conveniently illustrated by using numerical examples. The parameters and their values of population size is set to 200, generation limit is 10, cross over probability is 0.95 and mutation probability is 0.1 are set for ten number of trials. The frequency chart and cost chart are given in Table 6(a) and Table 6(b) respectively.

Table 6(a): Frequency chart for 10 locations 10 machines

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0	100	3	0	6	35	190	14	12	12
2		0	6	8	109	78	1	1	104	11
3			0	0	0	17	100	1	31	11
4				0	100	1	247	178	1	4
5					0	1	10	1	79	5
6						0	0	1	0	4
7							0	0	0	1
8								0	12	1
9									0	0
10										0

Table 6(b): Cost chart for 10 locations 10 machines

Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0	1	2	3	3	4	2	6	7	2
2		0	12	4	7	5	8	6	5	1
3			0	5	9	1	1	1	1	2
4				0	1	1	1	4	6	2
5					0	1	1	1	1	60
6						0	1	4	6	0
7							0	7	1	2
8								0	1	1
9									0	0
10										0

Office site

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

Tool room

Employee facilities

Figure 5: Plant layout 25 locations

16	12	8	4
17	5	1	7

16	9	5	10
17	1	2	6

15	2	9	6
14	13	10	19
18	11	3	20
Cost = $ 5806			

15	7	4	3
14	12	8	19
18	11	13	20
Cost = $ 5547			

16	14	7	4
17	1	5	8
3	6	2	9
13	15	10	19
18	12	11	20
Cost = $ 5800			

16	12	14	11
17	2	9	5
10	6	15	3
13	7	1	19
18	4	8	20
Cost = $5736			

16	9	2	5
17	3	6	10
14	11	1	7
15	8	4	19
18	12	13	20
Cost = $ 5819			

16	3	15	12
17	4	7	8
5	2	9	1
10	14	6	19
18	13	11	20
Cost = $5806			

Figure 6: Layouts for 25-location plant with fixed locations and excessive space

The optimal facility layout is shown for this example in Figure 5. Optimal material handling cost of $5275 is obtained. The effectiveness of using the algorithm for the case in which the number of machine cells to be placed is equal to the number of locations is available. In this case, all the location sites are of same shape and size. However, in real world situations such conditions are rare. Generally, some of the facilities or machines have to be fixed at certain locations. Requirement of certain facilities or machines must be located in certain fixed locations, may arise due to many reasons. For example, the relocation cost of a machine is too expensive so it has to stay in its original fixed location. To investigate the performance of genetic algorithm on plants with fixed location constraints, the previous 10 (2×5) location plant is used. Similarly, some spare space is included for possible future expansions. Expansions may result from surged market demand, inclusion of new product lines, or manufacturing of seasonal products etc. Thus layout model does consider the existence of such extra space and as a result possible effective layout are considered in different shapes such as shown in Figure 5. These odd shape layouts are usually obtained in plants with excessive space. If a plant has excessive space for machine allocation, the extra portion should also be included in the placement decision. Layout of plants with fixed location constraints and excessive space is considered here. Offices, temporary stock rooms, rest rooms and tool rooms are some of the facilities common to any manufacturing plant. These facilities may not be easy to relocate and hence restricted the machine allocations. Therefore, the space left for machine allocation is often irregularly shaped. A 20 (5×4) location plant is set up to accommodate three fixed facilities (occupying 5 locations), 10 machines and 5 excessive locations, as shown in Figure 5. The fixed locations and the excessive locations are introduced as dummy machines with zero frequency of interaction and zero interaction cost. Machines 1 to 10 are actual machines. Machines 16 and 17 are fixed in location 1 and 5 to occupy the office site. Machine 19 is positioned in location 17 for the tool room. Machines 18 and 20 are reserved for the employee facilities. The dummy machines 11, 12, 13, 14 and 15 are free to move around any unassigned locations. Experiments were performed for 10 times with same genetic parameters of the earlier example. The best layouts are shown in Figure 6. The optimal material handling costs in $ are given with each layout.

VIII. CONCLUSION

The intercell layout problem has been modeled as a quadratic assignment problem. One of the important data required for the intercell problem is the flow of material between the cells. The sequence of operations and the production volume of parts have been considered as two major factors that affect the flow of material between cells. A mathematical model available for calculating the material flow is used. An algorithm is developed to solve the formulated QAP. The performance of proposed algorithm is compared with other heuristics developed for facility layout problems. The proposed algorithm obtains optimum for problems considered. It outperforms in some of the solutions reported. Based on the experiments conducted, it is shown that the proposed algorithm performs better for extended facilities. Thus the restricted areas problems in cellular manufacturing problems are addressed and genetic algorithm methodology is applied.

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