JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

GENETIC ALGORITHM FOR SINGLE ROW LAYOUT PROBLEMS IN CELLULAR MANUFACTURING SYSTEMS

[1]Dr. Prafulla C. Kulkarni
[1]Principal.
[1]Deprtment of Mechanical Engineering.
[1]Gokhale Education Society's R. H. Sapat College of Engineering, Management studies and Research, Nashik, India

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 single row 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 single row layout problems. The computational results are given for some of the single row layout problems. Numbers of problems from literature are solved and results are compared. Gist of the issue is given in the conclusion.

Index Terms **– Cellular manufacturing, Intercellular layout, Genetic algorithm, Single row 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. 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 Kulkarni (2021)..

II. LITERATURE SURVEY AND MATHEMATICAL MODELLING

Kouvelis et al. (1995) attempted the single row layout problem in order to minimize the total backtracking distance. 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. Wang et al. (2001) formulated the facility layout problem in CMS environment in which the demand rate of products varies over the product's life cycle. The intracell and intercell layout problems are simultaneously considered through a nonlinear mathematical model using binary variables. The simulated annealing algorithm is further used to minimize the total material handling cost. Yu and Sarker (2003) proposed a directional decomposition heuristic for a linear machine-cell location formation. One dimensional equidistant problem, considering sequence of operation and equidistant location was formulated as QAP. 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. 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. In the present work, an attempt is made to deal with such issues in detail. 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). 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.

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

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

Constraints:

(1) Ensures that each location contains only one cell

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

(2) Ensures that each cell get only one location

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

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. In this paper, genetic algorithm is used to deal with layout problems.

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 single row / line 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 in Kulkarni and Shanker (2007).

IV. CHROMOSOME REPRESENTATION

The genetic algorithm requires a chromosome representation scheme as in Figure 1. The entire manufacturing plant/ department are divided into single grids and each grid represents a machine location. For example, in case of single row / line layout with single line, the location numbers are given in the direction of flow. For illustration in the Figure 1, 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. The number of alleles in the chromosome will be equal to the number of machine locations available. This is in detail given in Kulkarni and Shanker (2013).

Flow

1	2	3	4	5

(b) Line layout- single Chromosome structure of single row/ 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. The program is terminated when maximum generations are reached. This mutation scheme is an efficient scheme for solving single row layout problem. The methodology adopted for it is explained in the next session.

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 distance matrix for single row layout problem of four machines is given in Table 6. The data for flow matrix are obtained from route card and production volume from the planning department.

Table 6: Distance matrix for single row layout problem of four machines

	Machine 1	Machine 2	Machine 3	Machine 4
Machine 1	0	1	2	3
Machine 2	1	0	1	2
Machine 3	2	1	0	1
Machine 4	3	2	1	0

Table 7 (a): Input information for 18-parts and 12-machines

Part	Production Volume	Machine routes
P01	100	M1→M4→M2→M6
P02	120	M3→M5→M12→M10
P03	50	M2→M4→M12→M6
P04	45	M5→M8→M10
P05	60	M3→M5→M12→M6
P06	80	M4→M2→M4→M6
P07	90	M1→M5→M9
P08	120	M3→M7→M10→M4→M8
P09	140	M1→M4→M6
P10	180	M3→M12→M8→M10
P11	80	M2→M6→M2→M4→M6
P12	60	M11→M9→M10→M8
P13	70	M1→M4→M5→M7
P14	150	M2→M4→M6→M2→M6
P15	120	M3→M7→M9→M10
P16	120	M3→M10→M12→M9→M12
P17	100	M5→M10→M8→M9→M12
P18	90	M2→M8→M9→M10

Table 7(b): Flow of material for 18-parts and 12-machines

Flow	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0	0	310	90	0	0	0	0	0	0	0
2	0	0	0	360	0	330	0	90	0	0	0	0
3	0	0	0	0	180	0	240	0	0	120	0	180
4	0	180	0	0	70	450	0	120	0	0	0	50
5	0	0	0	0	0	0	70	45	90	100	0	180
6	0	230	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	120	120	0	0
8	0	0	0	0	0	0	0	0	190	225	0	0
9	0	0	0	0	0	0	0	0	0	270	0	220
10	0	0	0	120	0	0	0	160	0	0	0	120
11	0	0	0	0	0	0	0	0	60	0	0	0
12	0	0	0	0	0	110	0	180	120	120	0	0

The problem of 18 parts and 12 machines as reported in literature is given in Table 7 (a) for production volume and route chart. Table 7(b) gives the flow matrix of material based on this. The problem is to minimize the material handling flow in a single row layout arrangement. Genetic algorithm is used for this. The optimal flow reported in Adel El-baz (2004) is 11440 which is global optimal. The material handling flow obtained by Genetic algorithm near optimal is 12005. Both of the solutions obtained are shown in the Figure 4. The variation is rearrangement of some of the machines as evident from Figure 4.

Solution by Adel El-baz 11440 and the best chromosome arrangement is shown below.

6	2	4	1	8	10	12	5	9	3	7	11

Solution obtained by proposed algorithm 12005 and the best chromosome arrangement is shown below.

6	2	4	1	8	12	9	5	10	3	7	11

Figure 4: The optimal and near optimal solutions obtained single row layout

Table 8: Comparison of different facility layout methods with proposed GA

Problem no.	**No. of cells**	**Global optimum solution**	**Algorithms used in Wang and Sarker (2002)**			**3-pair comparison**	**Bubble search algorithm**	**Proposed GA**
			LB	MDIH	MMPH			
s-5	5	**351**	343	351	351	368	351	**351**
s-6	6	**607**	571	609	609	618	607	**607**
s-8	8	**1241**	1149	1241	1307	1325	1241	**1241**
s-10	10	**2579**	2341	2585	2684	2767	2579	**2579**
s-12	12	**4431**	4008	4431	4608	4834	4478	**4471**
s-15	15	**8942**	8002	8942	9558	9750	8942	9041
s-20	20	**21925**	19232	21856	23130	24146	21845	22344
s-25	25	**42349**	37048	42349	45078	46385	42349	43140

Table 9: Solution obtained on the problem instances of Sarker (2003)

Problem No.	**Best known value**	**Final Assignment**	**Proposed GA**	**Final Assignment**
o-5	150	2, 3, 5, 1, 4	150	2, 3, 5, 1, 4
o-6	292	2,3, 4, 5, 1, 6	292	3, 4, 5, 1, 6, 2
o-7	472	4, 1, 6, 5, 7, 3, 2	472	4, 1, 6, 5, 7, 3, 2
o-8	784	2, 6, 1, 4, 8 5, 7,3	784	2, 6, 8, 4, 1, 5, 3, 7
o-9	1034	2, 9, 5, 4, 7, 8,3,6,1	1034	2, 9, 5, 4, 7, 8,3,6,1
o-10	1402	1, 6, 5, 4, 3, 10,2,8,7,9	1414	1, 6, 5, 4, 3, 2,10,8,7,9
o-15	5134	5, 1, 4, 6, 7, 8, 14, 9, 11, 12, 13, 10, 15, 3	5254	1,5, 4, 6, 7, 8, 14, 12, 15, 11, 10, 13, 2, 3, 9
o-20	12924	10, 2, 7, 3, 8, 17, 14, 9, 13, 19, 20, 6, 15, 18, 5, 11, 16, 12, 1, 4	13482	10, 3, 2, 17, 13, 8, 9, 7, 14, 19, 6, 1, 12, 16, 15, 11, 5, 18, 4, 20

From Figure 5, it is observed the percentage deviation for large size problems is more. For problem size 10 to 20, it is moderately less. The percentage deviation is 1.051 which implies that the proposed algorithm is effective for such single row layout problems. The popularity of single row layout in the cellular manufacturing is due to the fact that the arrangement of machines in the GT flow line and GT cell type manufacturing can be treated as a single row layout.

Table 10: Solutions obtained on problem instances (Wang and Sarker, 2002)

Size	**Problem no.**	**Optimal**	**Proposed GA**	**Final Assignment**	**Deviation %**
5	s-5	351	351	2, 4, 1, 3, 5	0.0
6	s-6	607	607	2, 4, 1, 3, 5, 6	0.0
7	s-7	909	909	7, 6, 5, 4, 1, 3, 2,	0.0
8	s-8	1241	1241	7, 6, 5, 4, 1, 3, 2, 8	0.0
9	s-9	1830	1830	6, 7, 5, 4, 1, 3, 9, 2, 8,	0.0
10	s-10	2579	2579	8, 10, 7, 6, 5, 4, 3, 1, 9, 2	0.0
11	s-11	3359	3359	8, 11, 7, 10, 6, 4, 5, 3, 1, 9, 2	0.0
12	s-12	4431	4471	11, 8, 10, 7, 6, 4, 1, 5, 3, 12, 9, 2	0.90
13	s-13	5933	5954	8, 1, 9, 2, 3, 12, 13, 4, 5, 10, 7, 6, 11	0.35
14	s-14	7316	7397	8, 1, 12, 3, 9, 2, 5, 13, 4, 7, 10, 6, 14, 11	1.10
15	s-15	8942	9041	2,8,15,3,9,1,5,13,10,4,14,7,12,6,11	1.10

16	s-16	11019	11210	11, 8, 14, 10, 6, 16, 7, 12, 4, 15, 13, 9, 5, 3, 1, 2	1.73
17	s-17	13173	13409	8, 1, 16, 15, 2, 13, 9, 3, 4, 12, 17, 10, 6, 7, 5, 14, 11	1.79
18	s-18	15699	16056	14, 6, 11, 17, 7, 4, 5, 10, 15, 12, 16, 3, 13, 2, 9, 8, 18, 1	2.27
19	s-19	18704	19089	17, 10, 11, 7, 13, 4, 6, 5, 14, 16, 9, 12, 3, 18, 19, 1, 2, 8, 15	2.05
20	s-20	21845	22344	6, 7, 11, 10, 17, 5, 16, 13, 9, 14, 4, 12, 3, 19, 15, 18, 1, 20, 8, 2	2.28
21	s-21	24891	25527	1, 8, 9, 21, 20, 18, 12, 10, 16, 2, 3, 19, 15, 17, 13, 11, 5, 4, 6, 14, 7	2.55
22	s-22	28614	29341	21, 8, 16, 1, 19, 3, 18, 9, 17, 5, 12, 2, 10, 13, 15, 4, 14, 22, 20, 7, 6, 11	2.54
23	s-23	33046	33885	21, 8, 6, 5, 15, 23, 3, 18, 9, 2, 13, 19, 20, 1, 4, 10, 12, 16, 17, 14, 22, 11, 7	2.53
24	s-24	37498	38437	15, 8, 12, 18, 20, 2, 9, 13, 3, 17, 10, 16, 1, 22, 23, 4, 11, 24, 19, 5, 7, 6, 21, 14	2.50
25	s-25	42349	43140	11,22,14,7,13,6,23,12,24,17,16,10, 4,18,3,1,25,5,19,20,9,15,8,2,21	1.86
				Average	1.217

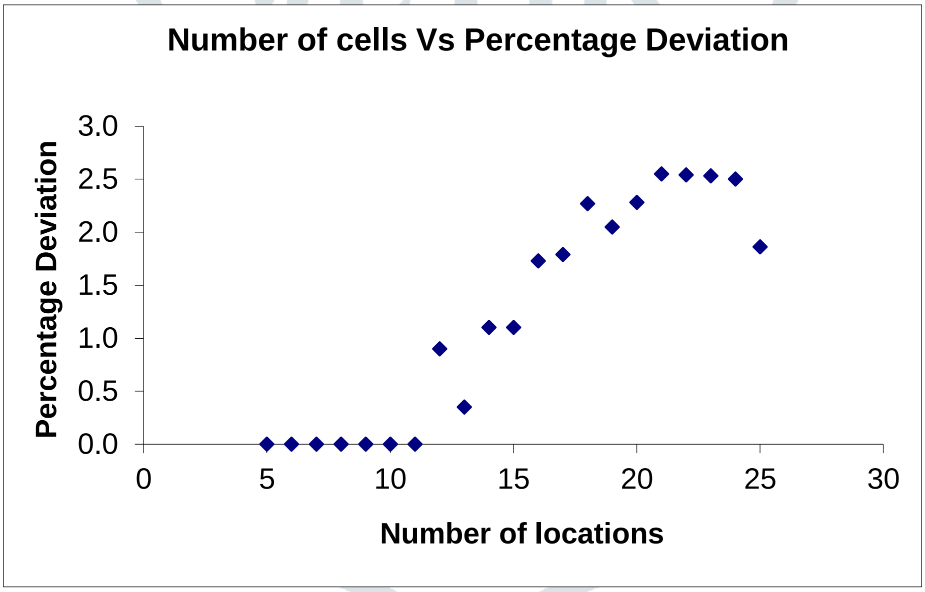

Figure 5: Number of cells vs. Percentage deviation

VII. 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 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. Intracell layout problem is also an important consideration for successful implementation of CMS. Single row layout pattern has been considered for the arrangement of machines within the cells. The algorithm used for intercell layout pattern is extended for intracell layout problem. The performance of the proposed algorithm is compared with the problems selected from the literature. The experimental results reveal that the proposed algorithm is effective for intra-cell layout problem. The popularity of single row layout in the cellular manufacturing is due to the fact that the arrangement of machines in the GT flow line and GT cell type manufacturing can be treated as a single row layout.

REFERENCES

[1] Adel El-baz, M., 2004. A genetic algorithm for facility layout problems of different manufacturing environments, *Computers & Industrial Engineering*, 47, 233-246.

[2] Kouvelis, P., Chiang, W., and Yu, G., 1995. Optimal algorithms for row layout problems in automated manufacturing systems, *IIE Transactions,* 27(1), 99-104.

[3] Sarker, B. R., 2003. Directional decomposition heuristic linear machine-cell location problem, *European Journal of Operational Research*, 148(3), 166-191.

[4] Sarker, B. R., and Xu, Y., 2000. Designing multi-product lines: job routing in cellular manufacturing systems, *IIE Transactions*, 32, 219-235.

[5] Wang, T. Y., Wu, K. B., and Liu, Y. W., 2001. A simulated annealing algorithm for facility layout problems under variable demand in cellular manufacturing systems, *Computers in Industry*, 46, 181-188.

[6] Wang, T. Y., and Sarker, B. R., 2002. Locating cells with bottleneck machines in cellular manufacturing systems, *International Journal of Production Research*, 40(2), 403-424.

[7] Kulkarni P.C.and Kripa Shanker, 2013. Genetic algorithm approach for solving intercellular layout problems in cellular manufacturing systems. IEEE Conference, DOI:10.1109/IEEM.2013.6962677.

[8] Wu, X., Chu, C., Wang, Y., and Yan, W., 2006b. A genetic algorithm for cellular manufacturing design and layout, *European Journal of Operational Research,* 181, 156-167.

[9] Yu, J., and Sarker, B. R., 2003. Directional decomposition heuristic for a linear machine-cell location problem, *European Journal of Operational Research,* 149, 142-184.

[10]Kulkarni P.C.and Kripa Shanker, 2007. A genetic algorithm for layout problems in cellular manufacturing systems. IEEE Conference, DOI:10.1109/IEEM.2007.4419279.

[11] Kulkarni P.C., 2021, Solving generalized groupings problems in cellular manufacturing systems by genetic algorithms, *Journal of Science and Technology*,DOI:10.46243/jst.2021.v6.i05.pp82-88.