Manufacturing Cell Formation Using Genetic Algorithm Technique

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Abstract:
In this research a genetic algorithm technique is used to form manufacturing cells. The cell formation involves forming a group of dissimilar machines and group of similar parts allocated to the same cell. The aim of this research is attempt to rearrangement of machines so that the inter-cellular movement can be minimized and increase group efficiency. Based on specific constraints and genetic algorithm a particular program was built by using MATLAB software (V8.3), to get the best solution to identify layout of manufacturing cells. The initial step of algorithm starting from generate the initial population randomly, then evaluated the fitness function and through crossover and mutations process is getting the next generation and iteration. This procedure to get the best solution. The research approach was applied in General Company for Hydraulic Industry "Dampers factory". It resulted in getting the desired results (reduced inter-cellular movement by formed 3 machine cells and 3 part families compared with incidence matrix) with increase in the efficiency of manufacturing cells from 64.77% at the begging and then increase reach 72.04% , note the improvement in efficiency of manufacturing .
Keywords: GT, Cell formation, Genetic algorithm, MATLAB, Fitness function.

1. Introduction

The verity in requirement of products, cause to development of world markets and technology for closing the needs of customers and demands. This is primer reason to appearance of group technology (GT) **[14].** Group technology was first submitted by Mitrofanov and then developed by Burbidge **[8].** The philosophy of group technology (GT) which identifies similar parts and gathers them together to take advantage of their similarities in manufacturing and design **[2].** GT close associated with many programs such as cellular manufacturing (CM), flexible manufacturing systems (FMS), Computer integrated manufacturing (CIM) and many other automation programs **[6].** Cellular Manufacturing system (CMS), representing the foundation for flexible manufacturing (FM) and just-in time (JIT) **[1].** It's that raised between a flexibility of functional manufacturing and the high production rate of liner manufacturing **[15]**. CMS shown in Fig. (1)

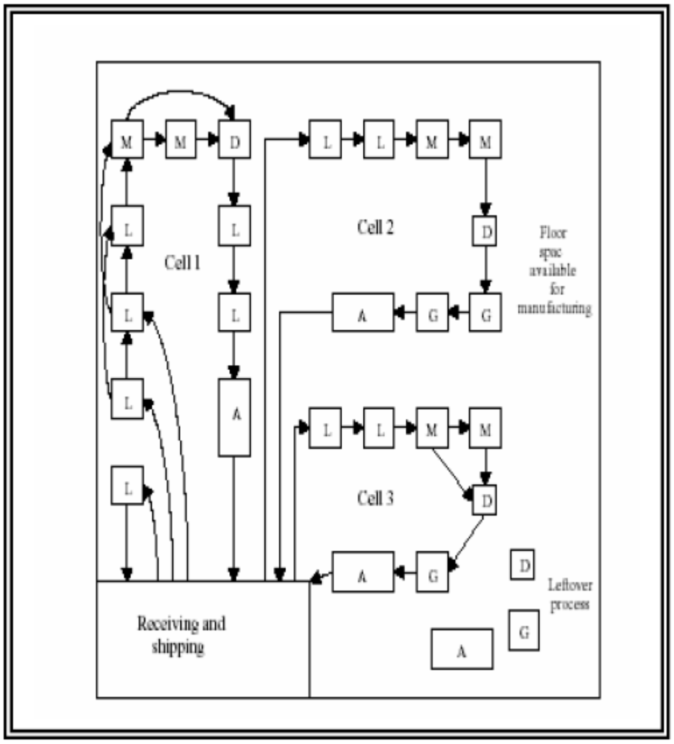


Fig. 1 Cellular Manufacturing System [3].

CMS consists of manufacturing cells its small manufacturing unit consists of: operators, dissimilar machine and equipment all of them gathered to produce similar products with lower lead time **[16]**. The benefits of cellular manufacturing include: setup time, material movement is reduced, increases speed of throughput or reduced throughput time and work-in-process is substantially reduced because of increase in speed of throughput, reduced setup time and waiting time **[7]**.The cell formation considers the prim/problem in making the cellular manufacturing (identifying groups of machines and parts families which process on these machines) **[10].** There are many approaches used to solve this problem these approaches can be divided into the following**:** Descriptive procedure such as (production flow analysis (PFA) and component flow analysis (CFA)), Mathematical programming, Heuristics, Metaheuristics, Hybrid Metaheuristics and Artificial intelligence approaches) **[4].** When manufacturing cells are designed taking into consideration certain criteria such as: **[3]**

Cell Size: Cells can be designed by choosing specific criteria such as: names, sizes and shapes, or process requirement. The cell size would have a big impact on the intercellular motion. The number of movements of large cells when the cell size is small, if the cell size were large, parts would be carried out to different machine within the same cell.

Intercellular Moving: Machinery group within the cell are rarely process all the families of the parts assigned to them. This requires that your need to allow some movement between groups in other cells or we increase the size of the groups by merging cells together to form new group. But controls of the manufacturing cells are difficult to compare with small-sized cells.

Product Mix: Each cell must be able to meet the production requirements of the parts of the families assigned to it. Change in product mix leads to increase the number of movements of the parts that need to run on machines located in another cell similar to the machines in the same cell operations, because the capacity in the first cell is not enough.

Lot Size: With conventional manufacturing methods, there is an inverse relationship between the size of the batch and costs of manufacturing. When the batch size is small there is a rise in the manufacturing cost due to the increase in cost of set-ups. The philosophy of group technology (GT) has canceled this inverse relationship between manufacturing costs and lot sizes. The manufacturing cell formation provides the ability to reduce the cost of the setup, where they are processing small batches of products that belong to the same family together.

2. The Cell Formation Problem

A 0-1 machine-part incidence matrix is used to model the manufacturing system **[5]**.The M refers m machines and the P columns denoted to the p parts **[17]**. Each element (a_{ij}) in the matrix is either 1 or 0 **[11]**.

$$a_{ij} = \begin{cases} 1 \text{ (if part i has an operation on machines j)} \\ 0 \text{ (otherwise)} \end{cases}$$

Machine-part incidence can be Shawn in Fig. (2)

M/P	P1	P2	P3	P4	P5
M1	1	0	0	1	0
M2	0	1	1	0	1
M3	0	1	1	0	1
M4	1	0	0	1	1

Fig. 2. Machine/Part Matrix

M/P	P1	P4	P2	P3	P5
M1	1	1	0	0	0
M4	1	1	0	0	1
M2	0	0	1	1	1
M3	0	0	1	1	1

Fig. 3. Result of GT Formation

Note that there is (1) outside the cell 2 in this case is called an (exceptional element) because it needs two or more machine sets , and machine 4 is called a ‘‘bottleneck machine’’ because it is processes more than parts families. There is also a (0) presented in cell 1 in Fig. (3), it is called a (void) . In this case, the grouping efficiency (η) is to define the quality of the solution, equation used to compute group efficiency is given below **[12]**:

$$\eta = q\eta_1 + (1-q)\eta_2$$

Where:

η_1 is the ratio of number of 1*s* in the diagonal blocks to each number of elements inside the diagonal blocks.

η_2 is the ratio of number of 0*s* outside diagonal blocks to the total number of elements outside diagonal blocks. An optimal result should have two features with a higher proportion of 1s inside the diagonal block as well as a higher proportion of 0s outside the diagonal block. q is a weighting factor ranging between $(0 \le q \le 1)$ and it is mostly suggested as 0.5. In general, an optimal result obtained for a machine/part matrix by a cell formation clustering method is desired to achive two conditions : **[17]**

(a) To reduce the number of 0s existing inside the diagonal bloc (voids).

(b) To reduce the number of 1s existing outside the diagonal blocks (exceptional elements).

3.Genetic Algorithms

Genetic algorithms are very active search algorithms based on the mechanics of natural chosen process **[6].** Genetic algorithm submitted by Goldberg was inspired by Darwin's theory of development which states that the survival of an organism is influenced by rule "the strongest species that survives" **[10]**. They have been applied very successfully to solve a wide range of intricate optimization problems. As the formation of manufacturing cells in cellular manufacturing is an intricate problem GAs are appropriate to this problem **[6].**

3.1 Components of Gentic Algorithmis

A typical GA consists of following steps: **[13]**

1. Generation initial population of (n) chromosomes randomly [encoded chromosomes].
2.Evaluated fitness function value of all of the chromosomes [selection] .
3. Genetic operation: The crossover and mutation operations are performed to generate offspring.
4. Repair strategy: evaluated fitness function values of each chromosomes.
5. at the end ,taken the best chromosome resulting during the complete evolutionary process **[16].**

3.1.1 The Representation of Chromosomes and Selection

In this research, The chromosomes are categorized into two types, part chromosomes and machine chromosomes. Machine high, respectively. The position gene represent the number of machine and chromosome length equal to the numbers of machines from low to the value of gene represent cell number; .Similarly, part chromosome the number of genes in a part chromosome is represent the number of parts. The gene value at a specific gene position of a part chromosome represents the cell number to which the interview part is assigned.

3.1.2 Crossover Operator

Crossover operator known how it is obtained genetic codes (offspring) by blended the chromosomes of parents (one–point, two–point, uniform crossover, etc). The chromosomes in Fig. (4) consist of six genes. The gene values in both the chromosomes are in between 1 and 3 because the number of machine cells 3. The offsprings by using two-point crossover method are shown in Fig. (5) .

Gen position	1	2	3	4	5	6
Machine chromosome 1	2	1	1	3	2	3
Machine chromosome 2	1	3	2	3	3	2

Fig. 4 Machine chromosomes

Gen position	1	2	3	4	5	6
Machine chromosome 1	2	3	2	3	2	3
Machine chromosome 2	1	1	1	3	3	2

Fig. 5 Machine chromosome after crossover

The machine offspring 1shown in Fig. (5) is obtained through copying the genes in the gene site 1 in the machine chromosome 1 and the genes in the gen site 2,3 and 4 in the machine chromosome 2 and the genes in the gene site 5 and 6 in the machine chromosome 1.Similarly, the machine offspring 2 is obtained through copying the genes in the gene site 1 in the machine chromosome 2, genes in the gene site
2,3,and 4 in the machine chromosome 1 and the genes in the gene site 5 and 6 in the machine chromosome 2. as well as to the part chromosomes

3.1.3 Mutation Operator

operator makes random changes in genetic codes of the offspring through selected two sites randomly from each offspring obtained after crossover of two chromosomes after that the swapping between them happen. Mutation include reordering of the list This is done based on a given probability for mutation like If the generated probability is less than or equal, for example 0.07, then mutation will be otherwise, the mutation do not be performed on the offspring **[9].** The offsprings obtained by mutation method are shown in Fig. (6) **.**

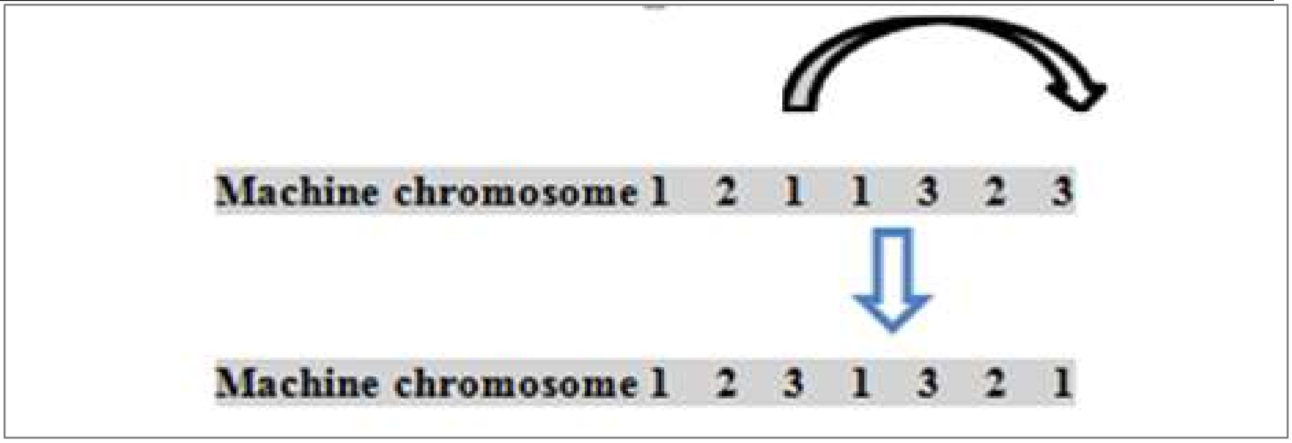


Fig.6 Machine Chromosome

4. Methoology

In this research, using genetic algorithm technique to generate manufacturing cell, parameters used in this research are as follow: generating initial population randomly; the length of the chromosomes is equal to the total number of machines;
Probability of crossover and mutation equal (0. 7 and 0.07) respectively; initial size = 20 and total number of generations =20, Fig. (7) show the flow chart of genetic algorithm methodology used in this research .

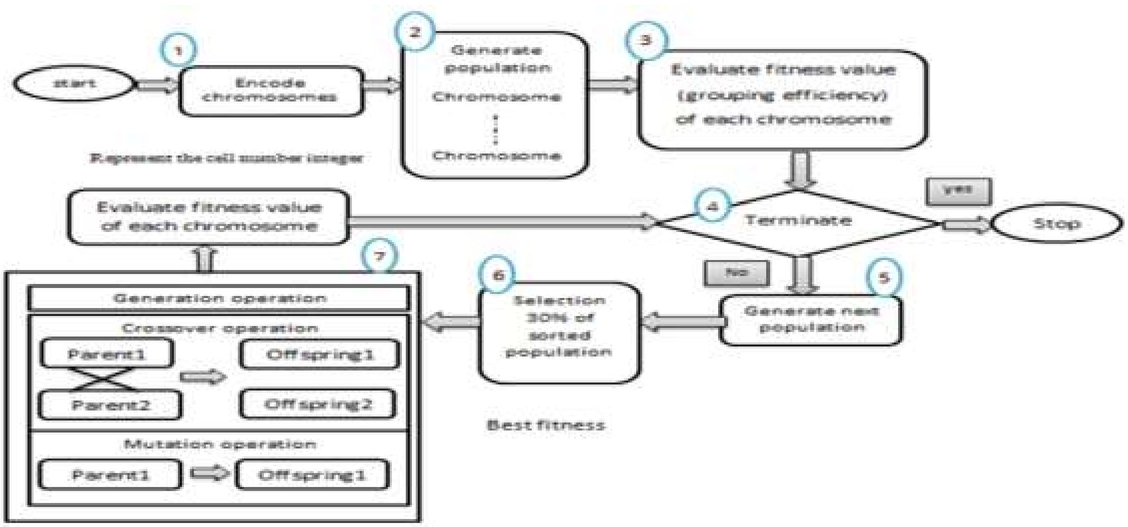


Fig.7 Genetic Algorithm Process Methodology

The methodology used are summarized in the fallowing :

Stage 1: Data Entry machines number (m), parts numbers (n) and machine-part incidence matrix [aij], population size of machine chromosomes (N1) similarly to the part chromosomes (N1) generation count (GC) = 1, and Maximum number of generations to be executed (MNG)) .

Stage 2: Find the upper number of cells (MC), [find the integer values of m/2 and n/2 rounded to next integer and find the lower of them].

Stage 3: initial population of machine chromosomes is generated by specify the machines to various cells from 1 to MC

Stage 4: Form machines groups and then based on the machine which it has the maximum number of operations specified a part to a machine cell

• If the machine groups numbers is equal to the parts families number, Then determine: Grouping efficiency then go to stage 5; otherwise, based on the parts groups obtained in stage 4 Form machine groups by: Assigning a machine to a part cell based on maximum number of parts;

• If the maximum number of parts processed by the machine equal, selection will be randomly.

• If the number of parts groups is equal to number of machine groups, find the desired measure of performance: (Grouping efficiency) and go to stage 5.

Stage 5: Collect parts groups and machines groups with each other and arranged in descending ordering of their fitness function values, grouping efficiency.

Stage 6: choose the upper 30% of the sorted population rounded to an even number and let the size of this subpopulation be N2.**[12]**

Stage 7: For all of the successive two machine chromosomes and parts chromosomes, perform the following.

- Perform crossover operation and mutation to obtain their corresponding offspring.

Stage 8: Store the machine offspring and part offspring of the subpopulation in respective chromosomes.

Stage 9: Sort part chromosomes and machine chromosomes together in decreasing order of their fitness function values.

Stage 11: increase the generation count by 1 (GC = GC + 1).

Stage 12: If MNG ≥ GC then go to Stage 6.

Stage 13: print the corresponding machine-component cell formation and the grouping efficiency.

5. Case Study and Implementation

Shock absorpation factory , a manufacturing workshop, is existing in Baghdad . used to produce Shocks absorber. Which consists of 8 parts . This manufacturing system consists of two area (processing area) and (Assembly area), it has several machine tools. The number of machines in the factory spread over the production department and assembly department. The process area includes three department and the rest of the machines to be distributed within the factory in factional layout .These department are as the follwing:

(welding department, presses department, and polishing department). Welding department include eight welding machines , such as : (PM1-PM2-PM6-PM8-PM10-PM11-PM13-PM14). The pressing department inclue six presses machine : (PM4-PM12-PM16-PM17- PM18-PM19) and polishing department include four machine : (AM18-AM19-AM20-AM21) Machine information data given in the table (1)

Table (1): Machine in the Factory

Machine code	Machine type
PM1	Welding machine
PM2	Circling machine
PM4	Air press machine
PM6	Spot welding machine simsik
PM8	Spot welding machine ARO
PM10	Welding machine P6-02-12
PM11	Welding machine (MIC)
PM12	Hydraulic press
PM13	Welding machine Esab
PM14	Welding machine national
PM15	Electrical vibrator
PM16	Mechanical press
PM17	Hydraulic press
PM18	Mechanical press
PM19	Electrical press

Table 1. continued

PM20	Grinding machine
PM21	Grinding machine
PM22	Thread rolling
PM23	Turning machine
PM24	Fired cutter machine AY-280
PM25	Fired cutter machine forte sab 240
PM26	Grinding machine
PM27	Swaging machine
PM28	Delotring machine (chamfering machine)
PM29	Grinding machine
PM30	Grinding machine

PM31	Drill
PM32	Turning machine
PM33	Electrical vibrator
PM34	Polishing machine
AM18	Polishing machine
AM19	Polishing machine
AM20	Polishing machine
AM21	Polishing machine

There are 22 machines that are used to process 8 parts produced. Table (2) show information about machine used and table (3) presents the data of 8 parts on machines by identifying operation sequence of machine and the rout sheet information to the product shown in table (4). The existing factory layout shown in Fig. (8)

Table 2. Machine Information

Machine	Machine code	Machine type
PM1	M1	Welding machine
PM2	M2	Circling machine
PM6	M3	Spot welding machine
PM12	M4	Hydraulic pressing
PM15	M5	Electrical vibrator
PM17	M6	Hydrulic pressing
PM19	M7	Elictrical press
PM20	M8	Grinding machine
PM21	M9	Grinding machine
PM22	M10	Threading machine
PM23	M11	Turning machine
PM24	M12	Fired cutter machine ay-280
PM25	M13	Fired cutter machine fort sab 240
PM27	M14	Swaging machine
PM28	M15	Dolotning machine
PM32	M16	Turning machine
PM33	M17	Electrical vabrator
PM34	M18	Polishing machine
AM17	M19	Washing machine (from assembly area)
AM19	M20	Polishing machine
AM20	M21	Polishing machine
L7	M22	Numbering machine (out factory)

Table 2. continued

Table 3 .Product Information

Part code	Part type	Sequence of machine
P1	Internal Cylinder	M13-M15
P2	Internal Washer	M12-M6-M17
P3	Body	M13-M15-M19-M22-M14-M2
P4	Ring	M13-M16-M5-M3-M1-M2
P5	Resirvor Head	M12-M6-M4-M5
P6	Shaft	M13-M11-M10-M8-M9-M20-M21-M18M7
P7	Washer	M9-M17
P8	Plate	M13-M16

Table 4. Machine Part Incidence Matrix

M/P	P1	P2	P3	P4	P5	P6	P7	P8
M1	0	0	0	1	0	0	0	0
M2	0	0	1	1	0	0	0	0
M3	0	0	0	1	0	0	0	0
M4	0	0	0	0	1	0	0	0
M5	0	0	0	1	1	0	0	0
M6	0	1	0	0	1	0	1	0
M7	0	0	0	0	0	1	0	0
M8	0	0	0	0	0	1	0	0
M9	0	0	0	0	0	1	0	0
M10	0	0	0	0	0	1	0	0
M11	0	0	0	0	0	1	0	0
M12	0	1	0	0	1	0	0	0
M13	1	0	1	1	0	1	0	1
M14	0	0	1	0	0	0	0	0
M15	1	0	1	0	0	0	0	0
M16	0	0	0	1	0	0	0	1
M17	0	1	0	0	0	0	1	0
M18	0	0	0	0	0	1	0	0
M19	0	0	1	0	0	0	0	0
M20	0	0	0	0	0	1	0	0
M21	0	0	0	0	0	1	0	0
M22	0	0	1	0	0	0	0	0

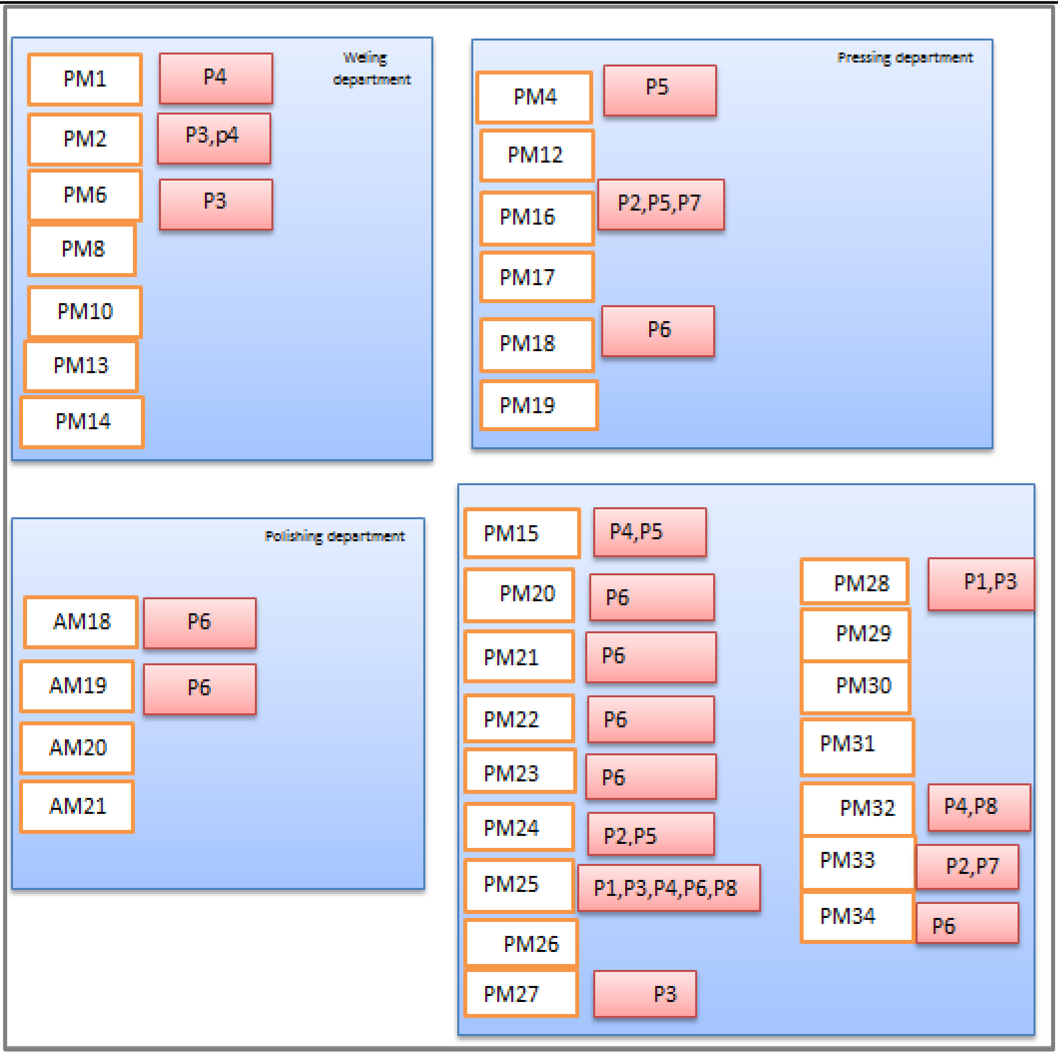


Fig. 8. Existing Manufacturing System

After the application of the proposed methodology to clustering machine into machine cells and part into part families we obtain three Machine cells and three parts families as following : machine cell (1) consist of [M5,M6,M12 ,M13,M15,M16,M17], machine cell (2) consist of [M2,M3,M4,M14,M19,M22] and machine cell (3) [M1,M7,M8,M9,M10,M11,M18,M20,M21], part family1 [P1,P2,P4,P5,P7,P8], part family 2 [P3] and part family 3 [P6]. The group efficiency increase from 0.6477 to the 0.7204

Machine chromosome	3 2 2 2 1 1 3 3 3 3 3 1 1 2 1 1 1 3 2 3 3 2

Fig. 9. Machine Chromosome

There are 22 digits in the chromosome showing 22 numbers of machines; manufacturing cell 1 (C1) has machines 5, 6,12,13,15,16& 17; manufacturing cell 2 (C2) has machines 2, 3,4,14,19 & 22, and manufacturing cell 3 (C3) has machines 1,7,8,9,10,11,18,20 &21 respectively.

Machin group1	5 6 12 13 15 16 17
Machine group2	2 3 4 14 19 22
Machine group3	1 7 8 9 10 11 18 20 21

Fig. 10. Machine Groups of Machine Chromosome.

Part chromosome	1 1 2 1 1 3 1 1

Fig.11. Part Chromosome

There are eight digits in the chromosome showing 8 numbers of parts; manufacturing cell 1 (C1) has parts 1, 2,4,5,7&8; manufacturing cell 2 (C2) has part 3 and manufacturing cell 3 (C3) has part 6 respectively.

Part group1	1 2 4 5 7 8
Part group2	3
Part group3	6

Fig. 12. Part Groups of Part Chromosome

The final matrix obtained and manufacturing cells show in Fig. [(13) and (14)] respectively .

M/P	P1	P2	P4	P5	P7	P8	P3	P6
M5	0	0	1	1	0	0		
M6	0	1	0	1	1	0		
M12	0	1	0	1	0	0		
M13	1	0	1	1	0	0	1	1
M15	1	0	0	0	0	0	1	
M16	0	0	1	0	0	1		
M17	0	1	0	0	1	0		

M2			1				1	
M3			1				0	
M4				1			0	
M14							1	
M19							1	
M22							1	
M1			1					0
M7								1
M8								1
M9								1
M10								1
M11								1
M18								1
M20								1
M21								1

Fig. 13. Final Solutin Matrix

It is observed from the output (final solution) matrix that parts p3, p4, p5 and p6 have exceptional element each (i.e. ones in off-diagonal blocks) and so part P3 have two exceptional element and one inter-cell move because both the exceptional elements belong to the same cell. The part P4 has three exceptional elements and two inter-cell move because both the exceptional elements belong to the same cell but one belong to another cell and the parts P5& P6 have one exceptional element and one inter-cell move because both the exceptional elements belong to another cell. Hence, there are seven exceptional elements and five inter-cell moves.

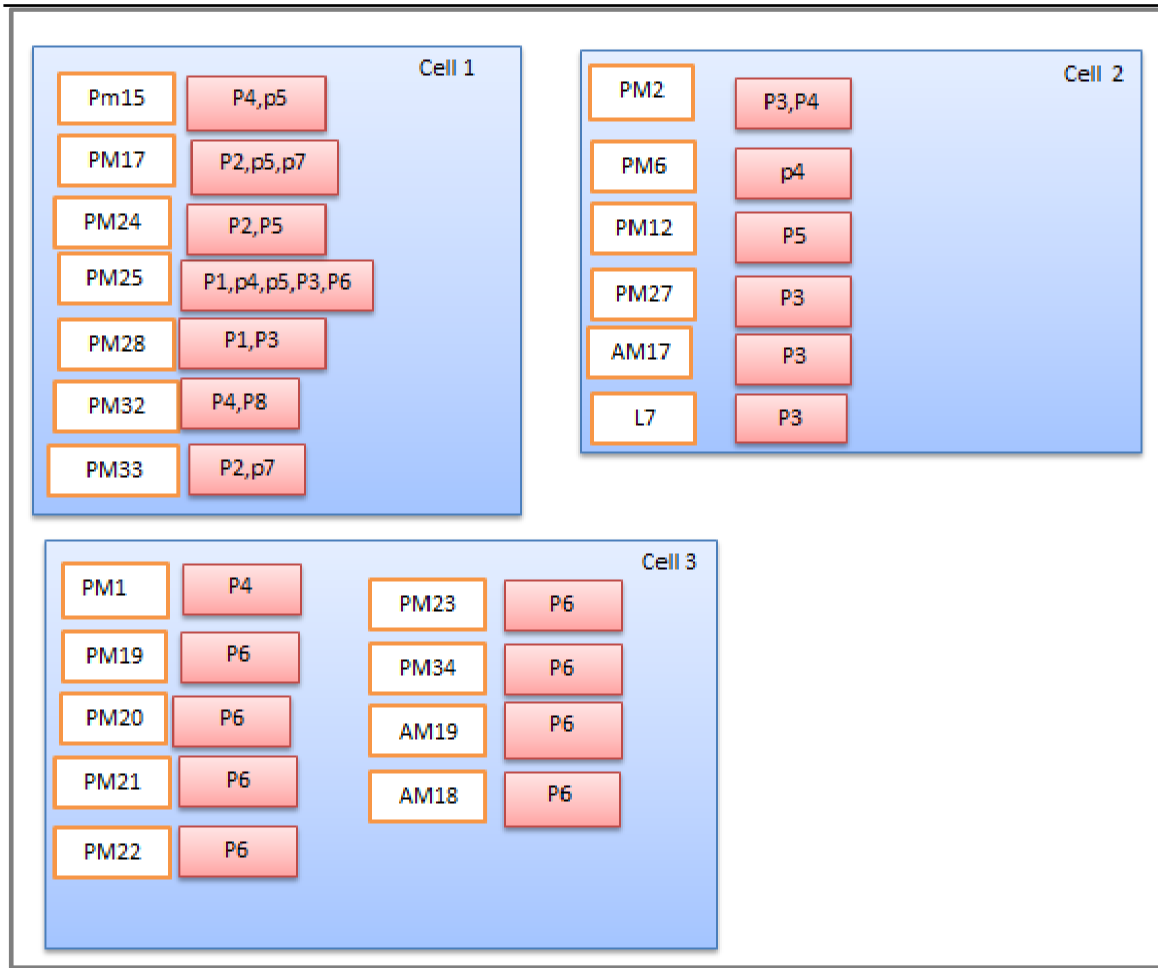
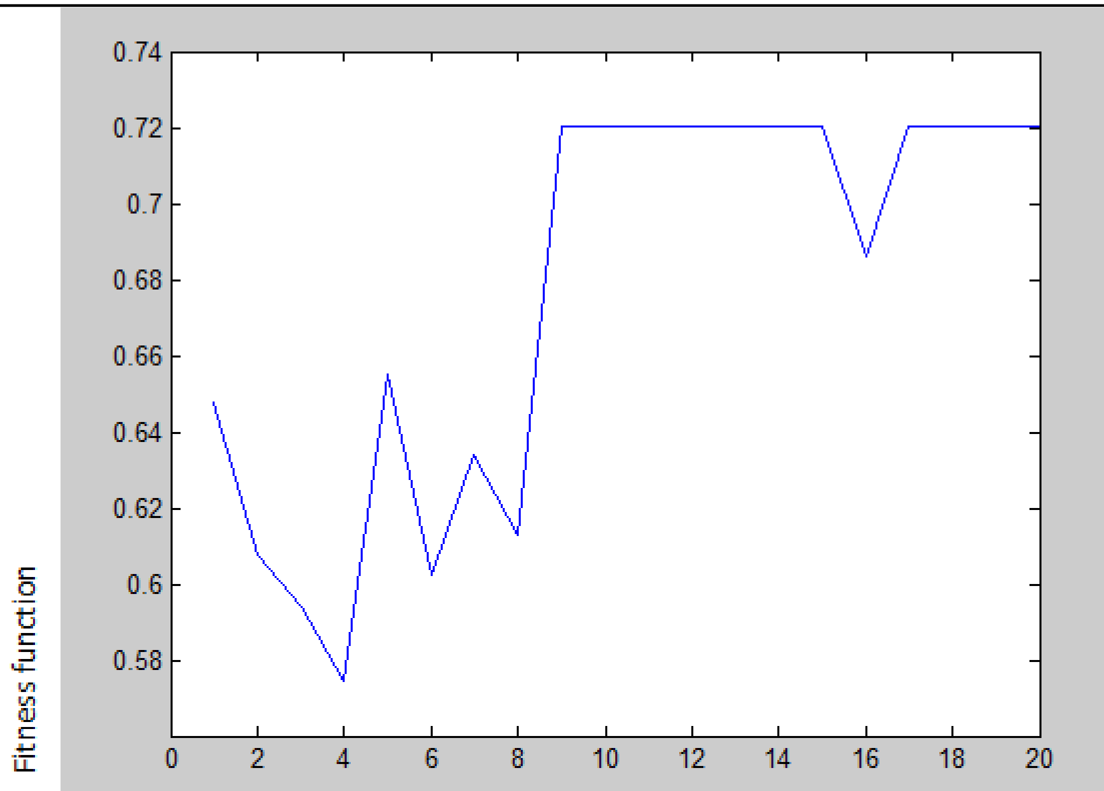


Fig. 14. Final Manufacturing Cells Formation

The maximum grouping efficiency at all generation can be show below in Fig. (15). The grouping efficiency at the begging is 0.6477 and then it increases reach 0.7204 . Note the improvement in efficiency of manufacturing cells is 7.27% .



Number of Iteration

Fig. 15. group efficiency at different iterations

6. Conclusions

The results obtained show :

1-The genetic algorithms very efficient technique in forming manufacturing cell because of Genetic algorithms optimization tools as they produce optimal or near optimal solutions not a single solution.

2- To compare the existing job shop manufacturing system and the new manufacturing cells design, can be noticed big difference in the number of machines in each plant layout, minimizing the number of machines used in the factory therefore there is improvement in plant layout. Short distances between machines and small lots make the material flow easier. This lead to reduction in inter-process handling costing.

3-Maximizing grouping efficiency because of decrease number of 0s inside the diagonal blocks and decrease the number of 1s outside the diagonal blocks (exceptional elements). This led to the required operations may be closed to only a small cell.

Reference

1- Akturk, S. M. , " Joint Cell Loading and Scheduling Approach to Cellular Manufacturing Systems", International Journal of Production

Research, Ankara, 2011,P. 6321–6341.

2- AL-Khateeb, J. N. H., " Facility

Layout Planning in A Lean Manufacturing Environment", Ms. thesis, University of Technology, Department of Production and Metallurgy Engineering, Baghdad,

2006.

3- Al-Rawi, M. H. A., " Propose an Algorithm For Manufacturing Cells Formation (MCF): A CIM Perspective", Journal Administration and Economy University of AL-Mustansiriya, ISSN:1813 6729,vol.33,Issue 84, June 2010, p.1-23.

4- Dhayef, D.H., " Computer Aided Group Technology Technique for Optimal Scheduling Plan in Production Environment", Ms. thesis, University of Technology, Department of Production and Metallurgy Engineering, Baghdad, 2015.

5- Hung, L. W., " Application of Genetic Algorithms to Group Technology", MS thesis, The Chinese University of Hong Kong, Department of Systems Engineering and Engineering Management, Hong Kong, 1996.

6- Jahanzaib, M. M., Syed, A. N., Shahid, A. K. and Shahbaz, M., " Application of Genetic Algorithm (GA) Approach in the Formation of Manufacturing Cells for Group Technology", Life Science Journal,2013, 9(4): 799-809 .

7- Lopez, L. M. A., " Design and Implementation of Cellular Manufacturing in a Jop Shop Environment", Ms. thesis, Massachusetts Institute of Technology Management , Cambridge,1997.

8- Mahdavi, I. , Teymourian, E. B., Nima ,T. ,and Kayvanfar ,V. , " An Integrated Model for Solving cell formation and Cell Layout Problem Simultaneously Considering New Situations ", Journal of Manufacturing Systems, Volume 32, Issue 4, October 2013, p. 655-663.

9- Margetts, "Adaptive Genotype to Phenotype Mappings for Evolutionary Algorithms" Cardiff University Department of Computer Science, ph. thesis , Cardiff, 2001

10- Nouri, H., and Hong, S. H., " A Bacteria Foraging Algorithm Based Cell Formation Considering Operation time", Journal of Manufacturing Systems, Volume 31, Issue 3, July 2012, P. 326–336.

11- Oliveira ,s., Ribeiro, j. f. f., and Seok, s .c.," A comparative study of similarity measures for manufacturing cell formation", Journal of

Manufacturing Systems , Volume 27 - Issue 1,July, 2008, p. 19-25.

12-Pachayappan, M., and Panneerselvam, R., " Hybrid Genetic Algorithm for Machine-Component Cell Formation", Intelligent Information Management, Vol.7 No.3, May 2015 p. 107-122.

13- Suer, G. A., Mese, E. M., and Egilmez, " Cell Loading, Family and Job Scheduling to minimize TT", International Conference on IML ,2011,p.1-8.

14- Taboun, M., " Development of Manufacturing Cells Using an Artificial Ant-Based Algorithm with Different Similarity Coefficients", Ms. *Thesis,* University of Windsor, Department of Applied Science, Windsor, *2011.*

15- Vakharia, A. J., " Methods of Cell Formation in Group Technology: A Framework for Evaluation", Journal of operation management, Volume 6, Issues 3–4, May–August,1986, p.259-271.

16-Wemmerlov ,U. and Johnson, D. J., "Cellular manufacturing at 46 User Plants: Implementation Experiences and Performance Improvements.", International Journal of Production Research, Volume 35, Issue 1, 1997, p.29-49.

17-Yang, M. S., and Yang, J. H., " Machine-Part Cell Formation in Group Technology Using a Modified ART1 Method", European Journal of Operational Research, Volume 188, Issue 1, July 2008, p. 140–152.

تكوين الخلايا التصنيعية باستخدام تقنية الخوارزمية الجينية

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الخلاصة:

في هذا العمل البحثي استخدمت الخوارزمية الجينية لتشكيل خلايا التصنيع. يتضمن تشكيل الخلايا تكوين مجموعة من المكائن الغير متشابهة ومجموعة من الاجزاء المتشابهة المخصصة للخلية المرغوبة. الهدف من هذا البحث محاولة لإعادة ترتيب المكائن لتقليل التنقل بين الخلايا وزيادة كفاءة المجموعة. اعتمادا على اعتبارات محددة و الخوارزمية الجينية تم بناء برنامج خاص باستخدام برنامج الماتلاب (V 8.3 (MATLAB) للحصول على افضل الحلول في تخطيط (layout) الخلايا التصنيعية. الخطوة الاولية للخوارزمية تبدأ من توليد الجيل الاول عشوائيا ومن ثم حساب دالة التقيم و من خلال عملية التهجين وتوليد الطفرات يتم الحصول على الجيل القادم و بتكرار نفس العملية وصولا الى الحل الافضل. تم تطبيق هذا البحث في الشركة العامة للصناعات الهيدروليكية في مصنع المخمدات تم الحصول على النتائج المطلوبة (تقليل التنقل بين الخلايا بالمقارنه مع (incidence matrix)) مع ملاحظة زيادة في كفاءة للخلايا التصنيعية من 64.77% الى 72.04% حيث نلاحظ التحسن في الكفاءة .