Applying assignment allocation algorithm to cell formation problems

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***Abstract*—In this paper, an iterative procedure based assignment allocation algorithmhas been employed to solve ten well-known benchmark cell formation problems. It is seen, through computation experimentation that the algorithm provides better grouping efficacy than those given by the state-of-the-art procedures.**

***Keywords*—Cellular manufacturing; group technology; machine-part cell formation; grouping efficacy;assignment allocation algorithm**

I. Introduction

Group technology (GT) is the formation of grouping of parts which are similar in design and production, resulting in better utilization of resources, improved productivity, product quality and manufacturing lead times while on the other hand, it reduces the work-in-progress inventory, setup time and material handling cost [1]. Another synonym for GT is cellular manufacturing (CM), though the use of this term has been discouraged by John L. Burbidge[2], as telling workers that they are going to be put into cells (prisons) can be counterproductive. The main objective of cell formation problem (CFP) is to minimize the inter-cellular movement of parts while on the other hand increasing the utilization of machines within the cells. CFP has been classified as NP-hard problem [3], hence, mostly meta-heuristic methods are applied for solving such problems.

The remainder of the paper is organized as follows: Section IIprovides a brief literature review on CFP and solution techniques. Section III and IV respectively presents brief description of CFP and different parameters for measuring performance. Section V explains the AAA with the help of a flowchart and a worked out example. The computational results and their comparison with established solutions are presented in section VI. Finally, section VII concludes the paper.

II. LITERATUREREVIEW

Adil, Rajamani & Strong [4] proposed the assignment allocation algorithm, which is based on iterative process. They compared their results with eight benchmark problems from the literature [5]. Apart from the iterative procedure, several other approaches such as simulated annealing [4, 9 – 10] genetic algorithm [6 – 8, 11, 33, 34], and tabu search [12] have been suggested. Recently, hybrid heuristics such as hybrid grouping genetic algorithm [13], hybrid genetic algorithm [14] and correlation analysis and relevance index (CARI) based approach [15] are being applied for solving CFP. Apart from this several other heuristic methods based on Euclidean distance matrix [35] and alternative routings [36] have also been proposed recently for solving CFP.

III. Problem Description

The CFP is generally formulated as a binary incidence matrix as shown in Table 1. In this example, rows represent parts (P_i) and columns represent machines (M_j). Elements of the binary matrix are 1 if a part i requires machining in machine j, otherwise its 0.

TABLE I. A 4 part – 4 machine incidence matrix

	M_1	M_2	M_3	M_4
P_1	1	0	1	0
P_2	0	1	0	1
P_3	1	0	1	0
P_4	1	0	1	0

The main objective of any CFP is to convert the machine-part incidence matrix into some diagonally arranged blocks where each block represents a combination of one machine cell and a part family group, so that the inter-cellular movements of parts decreases while at the same time the utilization of machines within the cell increases.

After diagonalization of the problem given in TABLE I using AAA, the block diagonal machine-part incidence matrix is obtained as shown in TABLE II.

IV. Performance Measure

The quality of the formed cluster is mostly evaluated by measuring grouping efficacy [16] or grouping efficiency [17]. In this paper single parameter, grouping efficacy (τ) has been chosen for comparison of the results with the results mentioned in [11]. Mathematically,

$$\tau = \frac{o - e}{o + v}$$

where,

- o = number of 1's in the incidence matrix
- e = number of exceptional element i.e number of 1's outside the cells in the solution matrix
- v = number of voids in the solution i.e number of 0's inside the cells in the solution matrix

TABLE II. SOLUTION OF THE CFP OF TABLE I

	M_1	**M_3**	**M_2**	**M_4**
P_1	1	1	0	0
P_3	1	1	0	0
P_4	1	1	0	0
P_2	0	0	1	1

V. ASSIGNMENT ALLOCATION ALGORITHM

The mathematical model is based on the objective of minimizing the weighted sum of voids and exceptional elements.

A. *Indices:*

p = parts (p = 1,2,3,...,P)

m = machines (m = 1,2,3,...,M)

c = cells (c = 1,2,3,...,C)

B. *Parameters*

- a_{pm}= 1 (if part *p* requires processing in machine *m*)
  = 0 (otherwise)
- P = Number of parts
- M = Number of machines
- C = Maximum number of cells that can be formed
- w = Fraction representing the weight on exceptional elements ($0 \leq w \leq 1$)
- (1 - w) = Fraction representing the weight on voids

C. *Variables:*

- x_{pc}= 1 (if part *p* is allocated to cell *c*)
  = 0 (otherwise)
- y_{mc} = 1 (if machine *m* is allocated to cell *c*)
  = 0 (otherwise)

D. *Mathematical model*

$$Min\ z = w \sum_p \sum_m \sum_c a_{pm} x_{pc}(1 - y_{mc}) + (1 - w) \sum_p \sum_m \sum_c x_{pc} y_{mc}(1 - a_{pm})$$

such that

$$\sum_c x_{pc} = 1; \forall p$$

$$\sum_c y_{mc} = 1; \forall m$$

$$x_{pc}, y_{mc} \in \{0,1\} \forall pmc$$

In AAA the above model is split into two sub-models:

- Allocation sub-model

$$Min\ z_1 = \sum_p \sum_m \sum_c B_{pmc} x_{pc}$$

where, $B_{pmc} = wa_{pm}(1 - y_{mc}) + (1 - w)(1 - a_{pm})y_{mc}$

such that

$$\sum_c x_{pc} = 1\ \forall p$$

$$x_{pc} \in \{0,1\}$$

- Assignment sub-model

$$Min\ z_2 = \sum_p \sum_m \sum_c D_{pmc} y_{mc}$$

such that,

$$D_{pmc} = wa_{pm}\left(1 - x_{pc}\right) + (1 - w)(1 - a_{pm})x_{pc}$$

$$y_{mc} \in \{0,1\}$$

The AAA is explained with the help of a flowchart (Figure. I) and a worked out example.

- *Step 1Iniput*Input to the part-machine matrix is shown in TABLE I. The following values were considered: w = 0.7, P = 4, M = 4, C = 5
- *Step 2 Initialization* The following initialization were made: i = 0, $OBJM^0$ = - 1000000, $OBJP^0$ = - 1000000
- *Step3 Initial assignment* Each machine is assigned to a separate cell leaving the last cell empty,i.e $y_{11}^0 = y_{22}^0 = y_{33}^0 = y_{44}^0 = y_{55}^0 = 1$ and all other y variables are set to 0. Hence, the values of y_{mc} are set here. Update the iteration number.
- *Step 4Allocation*In this step the parts are allocated to cells based on the machine assignment from step III, i.e x_{pc} values are evaluated using the values of y_{mc} from the last step. It is done in the following way:

Consider part 1 first, which corresponds to row 1 of the part-machine incidence matrix. The number of machines required by this part is $OP_1 = 2$ (sum of 1's in the row). The number of machines assigned to cell 1 is $NM_1 = 1$. Hence, the number of machines that can be utilized by part 1, if assigned to cell 1 is $UP_{11} = 1$, which leaves two exceptional elements and zero void. The number of exceptional elements and voids can also be calculated as $ep_{11} = OP_1 - UP_{11} = 2 – 1 = 1$; $vp_{11} = NM_1 - UP_{11} = 1 – 1 = 0$. Calculate the value of B_{pc}= w ep_{pc}+ (1 – w) $vp_{pc.}$ Therefore, $B_{11} = 0.7 \text{ x } 1 + (1 – 0.7) \text{ x } 0 = 0.7$.

Similar calculations for allocating part 1 to other cells are:

c = 2, NM_2= 1, UP_{12} = 0, ep_{12} = 2, vp_{12} = 1, B_{12} = 1.7

c = 3, NM_3= 1, UP_{13} = 1, ep_{13} = 1, vp_{13} = 0, B_{13} = 0.7

c = 4, NM4= 1, UP_{124} = 0, ep_{14} = 2, vp_{14} = 1, B_{14} = 1.7

Thus, assigning part 1 to cell 1 or 3 will give the minimum value of 0.7 as the objective function contribution. The tie is broken arbitrarily by allocating it to cell 1. Carrying out similar calculations for the rest of the parts give us allocations as shown in TABLE III.

- *Step 5 Assignment*

For the part allocation that was obtained in the last step, the machine assignment can be obtained by the following procedure which is illustrated with the help of machine 1. Since the parts are allocated in cells 1 & 2, so let's consider cell 1 for example. Cell 1 has parts 1, 3& 4. Hence, we have to consider rows, 1, 3& 4. The column corresponding to machine 1 is 1. The number of parts requiring machine 1 is $OM_1 = 3$ (which is the sum of 1's in column 1). The total number of parts in cell 1 is $NP_1 = 3$. The number of parts in cell 1 which require machining in machine 1 is $UM_{11} = 3$. Thus, the number of exceptional elements is $ep_{11} = OM_1 - UM_{11} = 3 – 3 = 0$ and the number of voids is $vp_{11} = NP_1 - UM_{11} = 3 – 3 = 0$. Calculate the value of D_{mc}= w e_{mc}+ (1 – w) v_{mc}= 0.7 x 0 + (1 – 0.7) x 0 = 0. The remaining calculations for this and the other machines can be carried out in a similar manner.

TABLE III. INTERMEDIATE RESULTS OF STEPS 2,3,4 & 5

i	Part allocation/ Machine assignment	Step	Cells					$OBJP^i$/ $OBJM^i$
			1	2	3	4	5	
0	Machine	2,3	1	2	3	4	-	-1000000
1	Part	4	P_1, P_3, P_4	P_2	-	-	-	2.8
	Machine	5	M_1, M_3	M_2, M_4	-	-	-	0
2	Part	4	P_1, P_3, P_4	P_2	-	-	-	0
	Machine	5	M_1, M_3	M_2, M_4	-	-	-	0
3	Part	4	P_1, P_3,	P_2, P_4	-	-	-	0
	Machine	5	M_1, M_3	M_2, M_4	-	-	-	0

Assignment and allocation steps were carried out iteratively until convergence was obtained in the third step. The above example is a perfect partition with no voids or no exceptional elements as shown in TABLE II.

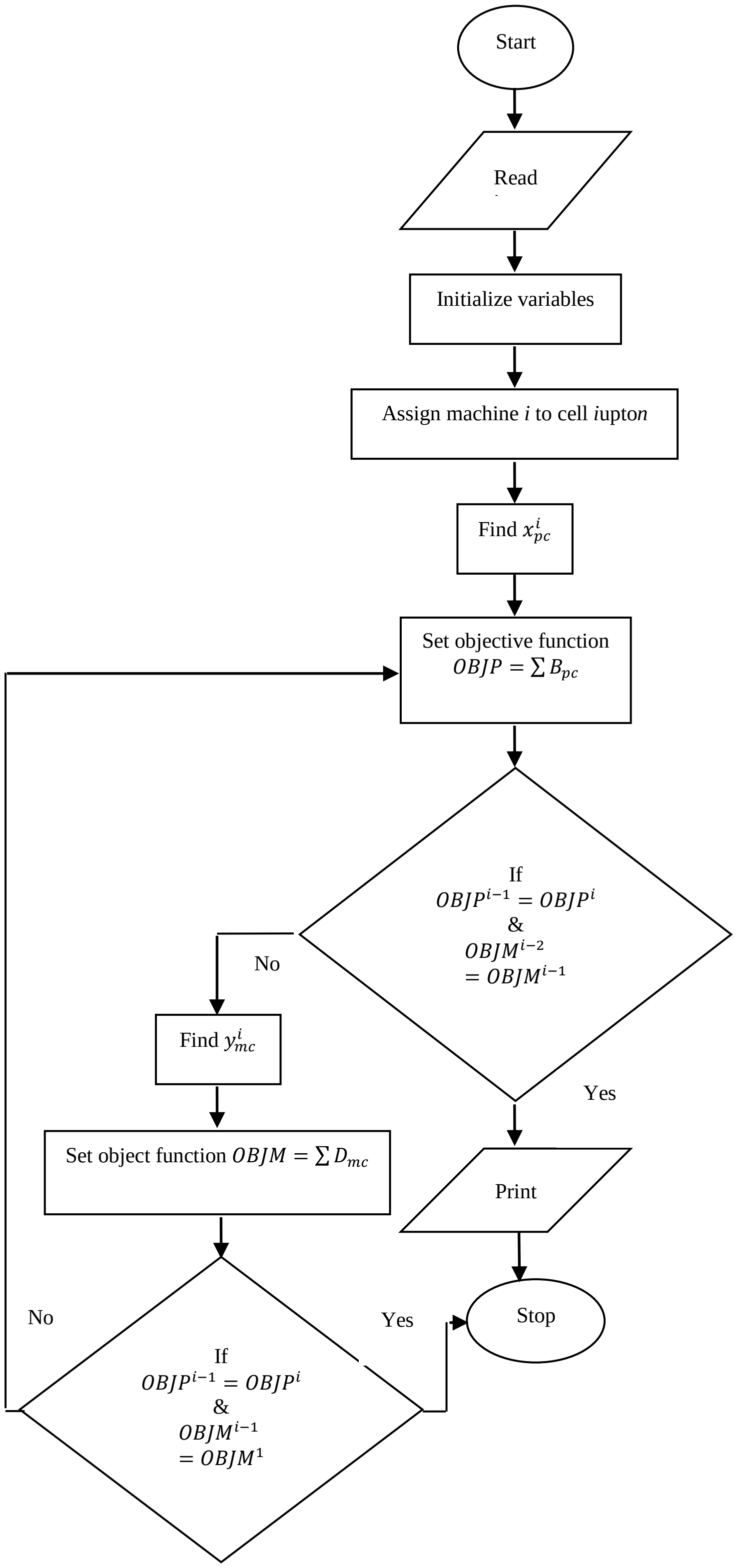

Figure I: Flowchart of Assignment Allocation Algorithm

VI. Comparison of Results

TABLE IV. Comparison of computational results with existing ones

Problem No	Source	Size M x P	ZODIAC [18]	GRAPHICS [19]	MST [20]	GATSP [21]	EA [22]	HA [23]	GA [11]	AAA
1	King et al [24]	5x7	73.68	73.68	-	-	73.68	73.68	73.68	80
2	Boctor [25]	7x11	70.37	-	-	70.37	70.37	70.37	70.83	72.73
3	McCormick et al [26]	16x24	32.09	45.52	48.70	-	52.58	51.96	45.10	53.41
4	Srinlvasan et al [27]	16x30	67.83	67.83	67.83	-	67.83	67.83	68.31	68.61
5	King [28]	16x43	53.76	54.39	54.44	53.89			54.86	57.32
6	Carrie [29]	18x24	41.84	48.91	44.20	-	54.46	54.95	55.91	56.60
7	Mosier et al [30]	20x20	21.63	38.26	-	37.12	42.96	43.45	42.31	43.20
8	Chandrasekharan et al [31]	24x40	17.61	41.67	44.17	42.50	44.87	44.85	45.21	45.77
9	Larry E. Stanfel [32]	30x50	46.06	56.32	58.70	56.61	59.66	59.66	59.76	60.00
10	King et al [24]	36x90	32.73	39.41	40.05	-	42.64	-	-	48.68

VII. Conclusion

The objective of the study is to employ the assignment allocation algorithm to different cell formation problems. This algorithm has been applied to some standard benchmark problems. It is found that in most of the cases, it outperforms the existing algorithms. The algorithm produces better solutions for six problems out of ten problems considered.

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