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Formation of machine-part cells using assignment allocation algorithm

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***Abstract*—In this paper, an iterative procedure viz. assignment allocation algorithm has been employed to cell formation problem by solving a nonlinear mathematical model. The algorithm has been applied to ten benchmark problems and through computational experimentation it has been observed that the algorithm provides better results for six of the problems that have been considered.**

Keywords—Cellular manufacturing; exceptional elements; void elements; machine-part cell formation; assignment allocation algorithm

I. Introduction

Group technology (GT) is the grouping of parts which are similar in design and production, which results in better utilization of resources, improves productivity, product quality, manufacturing lead times while on the other hand it reduces the setup time, material handling cost, work-in-progress inventory and material handling cost [1]. Group technology is also known as cellular manufacturing (CM). However John L. Burbidge discourages the use of the term cell as telling workers that they are going to be put into cell (prison) can be counterproductive [2]. The main objective of cell formation problem (CFP) is to maximize utilization of machines within cells and minimize intercellular movements of parts. CFP has been classified as NP-hard problem [3], so mostly meta-heuristic methods are employed for solving such problems.

The remainder of the paper is organized as follows: Section II provides 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. Literature review

An algorithm, known as assignment allocation algorithm (AAA), based on iterative process was proposed by Adil, Rajamani& Strong [4]. They compared their result with those of [5]. Several other approaches which are based on simulated annealing [4, 6 – 7], genetic algorithm [8 – 13], tabu search [14], heuristic methods based on Euclidian distance matrix [15] and alternative routings [16], hybrid heuristics such as hybrid grouping genetic algorithm [17], hybrid genetic algorithm [18]and correlation analysis and relevance index (CARI) based approach [19] have also been proposed for solving CFP.

III. Problem Description

The CFP is generally formulated as a binary incidence matrix as shown in TABLE I. 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 require 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 maximize the intracellular machine utilization whereas minimize the intercellular part movements. This can be achieved by converting the machine-part incidence matrix into some diagonally arranged blocks. Each block represents a combination of one machine cell and a part family group. TABLE II represents the solution of the problem in TABLE I, which is obtained using AAA.

IV. Performance measure

The quality of the formed cluster is mostly evaluated by measuring grouping efficacy [20] or grouping efficiency [21]. In this paper single parameter, grouping efficacy (τ) has been chosen for comparison of the results with the results mentioned in [11].

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

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

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

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,

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

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

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

Step I. Input

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 II. Initialization

The following initialization were made: i = 0, $OBJM^0$ = - 1000000, $OBJP^0$ = - 1000000

Step III. 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 IV. Allocation

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 x 1 + (1 – 0.7) 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, NM_4= 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 V. 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 $D_{mc} = w\, e_{mc} + (1 - w)\, v_{mc} = 0.7 \times 0 + (1 - 0.7) \times 0 = 0$. 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 1	2	3	4	5	$OBJP^i/OBJM^i$
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.

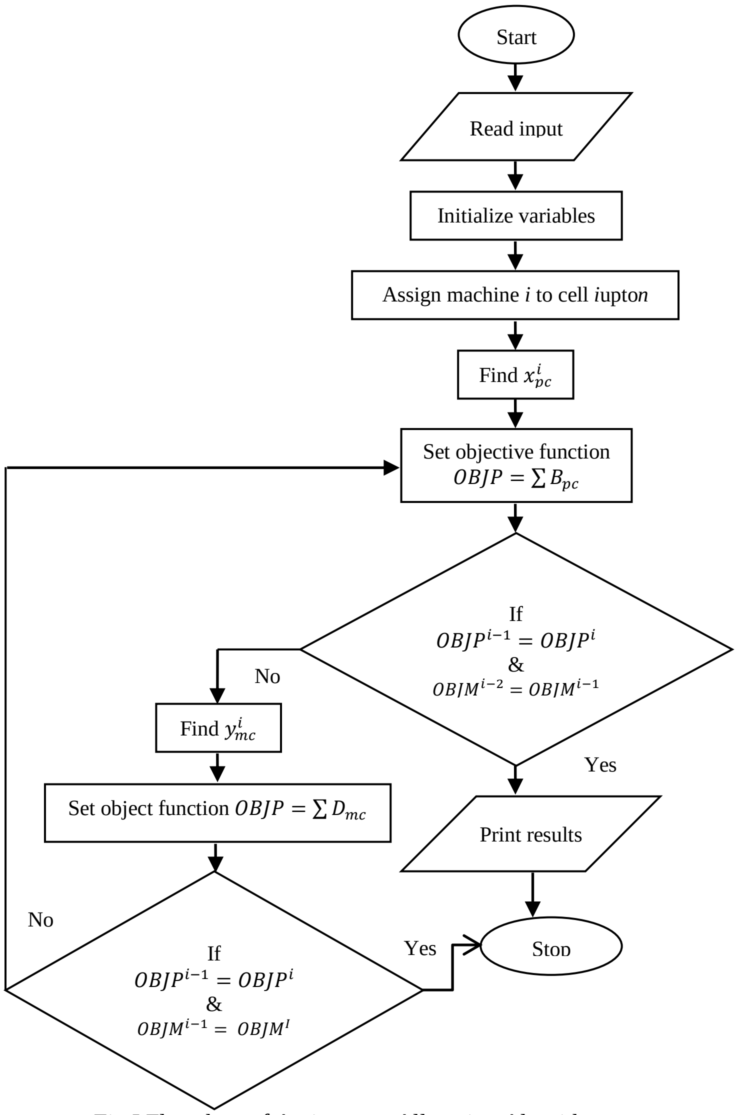

Fig.I Flowchart of Assignment Allocation Algorithm

VI. COMPUTATIONAL RESULTS AND THEIR COMPARISON

TABLE IV. COMPARISON OF COMPUTATIONAL RESULTS WITH EXISTING ONES

Problem No	Source	Size (M×P)	ZODIAC[22]	GRAPHICS[23]	MST[24]	GATSP[25]	GA[11]	AAA [35]
1	King et al [26]	5×7	73.68	73.68	-	-	73.68	80
2	Boctor [27]	7×11	70.37	-	-	70.37	70.83	73.91
3	McCormick et al [28]	16×24	32.09	45.52	48.70	-	45.10	52.58
4	Srinlvasan et al [29]	16×30	67.83	67.83	67.83	-	68.31	72.86
5	King [30]	16×43	53.76	54.39	54.44	53.89	54.86	57.32
6	Carrie [31]	18×24	41.84	48.91	44.20	-	55.91	57.00
7	Mosier et al [32]	20×20	21.63	38.26	-	37.12	42.31	43.80
8	Chandrasekharan et al [33]	24×40	100	100	100	100	100	100
9	Larry E. Stanfel [34]	30×50	46.06	56.32	58.70	56.61	59.76	59.88
10	King et al [26]	36×90	32.73	39.41	40.05	-	-	47.89

TABLE V. COMPUTATIONAL RESULTS

Problem number	Cell Number	Part family	Machine cell
1	1	P_2, P_4, P_5, P_6	M_1, M_4
	2	P_1, P_3	M_2, M_3
	3	P_7	M_5
2	1	P_1, P_3, P_7	M_1, M_5
	2	P_2, P_6, P_9	M_2, M_3
3	1	P_1, P_3, P_7, P_{10}, P_{13}, P_{15}, P_{18}, P_{22}, P_{23}	M_1, M_6, M_8
	2	P_{17}	M_2
	3	P_{16}, P_{19}	M_3, M_4, M_7
	4	P_5	M_9
	5	P_{21}	M_5
	6	P_2, P_8, P_{11}	M_{13}
	7	P_4, P_6, P_{12}	M_{14}
4	1	P_2, P_4, P_7, P_9, P_{12}, P_{18}, P_{22}, P_{30}	M_1, M_4, M_7, M_8, M_{11}, M_{12}
	2	P_1, P_3, P_{10}, P_{13}, P_{16}, P_{20}	M_2, M_{13}
	3	P_5, P_{23}, P_{25}, P_{27}, P_{28}, P_{29}	M_3, M_6, M_9, M_{15}
	4	P_5, P_{17}, P_{19}	-
	5	P_6, P_8, P_{11}, P_{14}, P_{15}, P_{21}, P_{24}, P_{26}	M_5, M_{10}, M_{14}, M_{16}
5	1	P_3	M_{13}
	2	P_2, P_4, P_{10}, P_{18}, P_{28}, P_{32}, P_{37}, P_{38}, P_{40}, P_{42}	M_2, M_9, M_{16}
	3	P_6, P_7, P_{17}, P_{34}, P_{35}, P_{36}	M_3, M_{14}
	4	P_5, P_8, P_9, P_{12}, P_{14}, P_{15}, P_{19}, P_{21}, P_{23}, P_{29}, P_{33}, P_{41}, P_{43}	M_4, M_5, M_6, M_8, M_{15}
	5	P_{16}	-
	6	P_1, P_{13}, P_{25}, P_{26}, P_{31}, P_{39}	M_7, M_{10}
6	1	P_{17}, P_{18}, P_{22}	M_1, M_2, M_8
	2	P_{19}	M_{16}, M_{17}
	3	P_1, P_2, P_3, P_4, P_5, P_6, P_7, P_{16}	M_3, M_4, M_5, M_6, M_7
7	1	P_7, P_{18}	M_1, M_7, M_{16}, M_{20}
	2	P_2, P_{10}, P_{13}, P_{14}	M_2, M_{10}, M_{11}, M_{13}, M_{17}, M_{19}
	3	P_5, P_{15}, P_{20}	M_3, M_8
	4	P_3, P_8, P_{11}, P_{12}, P_{17}	M_4, M_{14}, M_{15}, M_{18}
	5	P_{16}	M_5
	6	P_1, P_4, P_6, P_9	M_6, M_9
8	1	P_1, P_9, P_{16}, P_{17}, P_{33}	M_1, M_{13}, M_{21}, M_{22}
	2	P_{10}, P_{13}, P_{14}, P_{22}, P_{35}, P_{36}	M_2, M_5, M_{11}, M_{19}
	3	P_2, P_{11}, P_{12}, P_{15}, P_{23}, P_{24}, P_{31}, P_{34}	M_3, M_{20}
	4	P_8, P_{19}, P_{21}, P_{28}, P_{37}, P_{38}, P_{39}	M_4, M_{16}
9	1	P_1, P_{18}	M_1, M_4, M_{11}
	2	P_2, P_3, P_9, P_{17}	M_2, M_5, M_9, M_{13}
	3	P_4, P_6, P_8, P_{10}, P_{11}	M_3, M_{10}
10	1	P_{16}, P_{34}, P_{50}	M_1

VII. CONCLUSION

The objective of the study was to employ the assignment allocation algorithm to different cell formation problems. This algorithm has been applied to some standard benchmark problems. It can be observed from TABLE III that in most of the cases it outperforms the existing algorithms. However, from TABLE IV, which shows the cells with their corresponding parts and machines, it can be observed that in problem nos. 4 & 5 the algorithm exposes its inherent drawback where it forms cells without assigning any machine to them. So it can be concluded that the algorithm cannot be employed in all cell formation problems.

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