The Impact of Grouping Efficiency Measures in Cellular Manufacturing Systems

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Abstract

The worth of machine-part groups in cellular manufacturing systems is evaluated by different grouping measures available in the literature. Three of the well-known grouping efficiency measures will be used, analyzed and tested against two case studies taken from the literature to compare the effectiveness of cell formation. In this paper it is found that in both cases grouping efficiency measures may not lead to choose the optimal or best distribution. For that in the first case the designer will choose the optimal distribution based on optimality rather than efficiency. While in the second case his decision will be based on the constraints on the shop floor. Moreover, it is found that these measures have some deficiencies comparing to optimal manufacturing systems having the same sum of voids and exceptions.

Keywords

Cell Formation, Grouping Measures, Optimal Solution, alternative optimal solution

1. Introduction

Group technology (GT) is a method of organizing and using information about component similarities to improve the production efficiency of small to medium batch oriented manufacturing systems (Askin and Chiu 1990). The main idea of GT is to capitalize on similar manufacturing processes and features where similar parts are grouped into a part family and manufactured by a cluster of dissimilar machines (Wu 1998).
The input to the GT problem is a zero-one matrix A where $a_{ij} = 1$ indicates the visit of component j to machine i, and $a_{ij} = 0$ otherwise. Grouping of components into families and machines into cells results in a transformed matrix with diagonal blocks where ones occupy the diagonal blocks and zeros occupy the off-diagonal blocks. The resulting diagonal blocks represent the manufacturing cells. The ideal situation is one in which all the ones are in the diagonal blocks and all the zeros are off the diagonal blocks (Nair and Narendran 1998). However, this situation is rarely accomplished in practice. Therefore, the most desirable solution of cellular manufacturing systems is that which gives minimum number of zeros entries inside a diagonal block [known as voids] and minimum number of ones entries outside the diagonal blocks [known as the exceptional elements] (Kumar and Chandrasekharan 1990). Voids and exceptional elements have advance implications in terms of system operations (for more details see Adil *et al*. 1996). The effectiveness of a solution is usually measured by its grouping efficiency (Chandrasekaran and Rajagopalan 1986) or grouping efficacy (Kumar and Chandrasekaran 1990) or comprehensive grouping efficacy (Mukattash *et al* 2016) or the total number of voids in the diagonal blocks and number of ones outside the blocks (Viswanathan 1995). Grouping efficacy is

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used as a standard measure for evaluating solutions based on a binary part-machine matrix, which does not consider ordinal data (Kichun Lee and Kwang-Il Ahn (2013). Kellie et *al* (2007) pointed out that the quality of machine and part groupings have been evaluated using various objective functions, including grouping efficacy, grouping index, grouping capability index, and doubly weighted grouping efficiency (Al-Bashir et *al* 2018), among others'. Moreover, they developed a grouping genetic algorithm and found that although there are many researchers working to optimize cell formations using efficiency measures, cells formed this way do not always demonstrate optimized factory measures. Since the GT problem is of multi-objective nature, various objectives have been proposed such as minimizing the number of intercell movements, the number or cost of machines duplicated, the number of exceptional parts, machine utilization imbalance, or maximizing summed similarities and machine utilization (for more details see Grammatoula and Wilson(2011)).

The purpose of grouping efficiency measures is to evaluate the cell distribution in order to help the designer to choose the optimal or best distribution.
In this paper two different case studies of cells distributions with different parameters were studied and analyzed. In the first case it is found that the highest value of the performance measure may not lead to choose the optimal system (minimum sum of voids and exceptions). We can conclude that there is a contradiction between cells formed based on optimality or based on efficiency.
In the second case, we have two different systems with similar

- sum of voids exceptions,
- sparsity and
- number of cells, with different number of operations inside the cells.

While the number of operations in the Machine-Part matrix is different. In order to choose one of the two systems, the designer may not depend on grouping efficiency since they may give conflict evaluations for both distributions. In this case the designer will choose the distribution based on the shop floor's constraints.

2. Available Measures for Goodness of Cells

The measures for goodness of cells available in the literature are: Grouping Efficacy (τ) (Kumar and Chandrasekharan, 1990) and Grouping capability index (GCI) (Hsu 1990), *Grouping Index* (γ), Nair and Narendran, (1996).

The following definitions will be used in this paper:

Block: A sub-matrix of the machine component incidence matrix formed by the intersection of columns representing a component family and rows representing a machine cell.
Voids (v): A zero element appearing in a diagonal block.
Exceptional element (or exception) (**e**): A one appearing in the off - diagonal blocks.
Perfect block-diagonal form: A block diagonal form in which all diagonal blocks contain ones and all off-diagonal blocks contain zeros. Kumar and Chandrasekhoran (1990)
Sparsity (*Block* diagonal space) (**B**): Total number of elements within the diagonal blocks of the solved matrix, Sarker and Khan (2001).
Optimal solution: A system that contains minimum sum of voids and exceptions in the solved matrix
Alternative optimal solution: Two or more optimal systems having same sum of voids and exceptions in the solved matrix, Mukattash (2000)

In this paper optimal clustering's of machines and optimal groupings of parts into families are defined as the formed cell (manufacturing system) which has minimum sum of voids and exceptions.

3. Sensitivity analysis of optimal manufacturing systems

To analyze and study the optimality of manufacturing systems, a case study has been borrowed from the literature.

3.1 Illustration 1

The case study contains seven machines and eleven parts and its machine – part matrix is given below in Figure 1. This case study is provided by Boctor (1991). Different algorithms will be used to form 2, 3, 4 and 5 cells as shown below in figures 2 to 6. All these distributions are optimal. The 2-cell formation has an alternative optimal solution.

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The designer likes to choose the optimal distribution among these cells (the optimal number of cells is a manufacturing system with minimum sum of voids and exceptions) taking into consideration the shop floor's constraints. Some of these constraints are cell size, labor relations, and Physical, technological, organizational and economic constraints. Different grouping measures will be used to evaluate the efficiency of these cells in order to help him to take the right decision. In this case the number of operations in the solved matrix will be constant for all cells. While the number of operations inside the cells, sparsity and (e+v) are variable. For the two cells, since we have two alternative optimal solutions, then number of cells, number of operations inside the cells and (e+v) are constant.

		PARTS										
		1	2	3	4	5	6	7	8	9	10	11
MACHINES	1	1	0	1	0	0	0	1	0	0	0	1
	2	1	1	0	0	0	1	0	0	0	0	0
	3	0	1	0	0	0	1	0	0	1	0	0
	4	0	0	0	1	1	0	0	0	0	1	0
	5	0	0	1	0	0	0	1	0	0	0	0
	6	0	0	1	1	0	0	0	0	0	0	1
	7	0	0	0	0	1	0	0	1	0	1	0

Fig (1): machine-part matrix for the numerical example.

- **2-cell formation**

The two optimal alternative solutions for the 2-cell formation are shown below in figure 2 and 3 solved by Mukattash *et al.* (2011).

		PARTS										
		1	2	3	6	7	9	4	5	8	10	11
MACHINES	1	1	0	1	0	1	0	0	0	0	0	1
	2	1	1	0	1	0	0	0	0	0	0	0
	3	0	1	0	1	0	1	0	0	0	0	0
	5	0	0	1	0	1	0	0	0	0	0	0
	4	0	0	0	0	0	0	1	1	0	1	0
	6	0	0	1	0	0	0	1	0	0	0	1
	7	0	0	0	0	0	0	0	1	1	1	0

Fig (2): First optimal solution for the 2-cell

		PARTS										
		3	4	7	11	1	2	5	6	8	9	10
MACHINES	1	1	0	1	1	1	0	0	0	0	0	0
	4	0	1	0	0	0	0	1	0	0	0	1
	5	1	0	1	0	0	0	0	0	0	0	0
	6	1	1	0	1	0	0	0	0	0	0	0
	2	0	0	0	0	1	1	0	1	0	0	0
	3	0	0	0	0	0	1	0	1	0	1	0
	7	0	0	0	0	0	0	1	0	1	0	1

Fig (3): Second optimal solution for the 2-cell

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- **3-cell formation**

The optimal solution for the 3 -cell formation is shown below in figure 4, and solved by Wafik *et al.* (2008).

		PARTS										
		3	7	11	1	2	6	9	4	5	8	10
MACHINES	1	1	1	1	1	0	0	0	0	0	0	0
	5	1	1	0	0	0	0	0	0	0	0	0
	6	1	0	1	0	0	0	0	1	0	0	0
	2	0	0	0	1	1	1	0	0	0	0	0
	3	0	0	0	0	1	1	1	0	0	0	0
	4	0	0	0	0	0	0	0	1	1	0	1
	7	0	0	0	0	0	0	0	0	1	1	1

Fig (4): Optimal solution for the 3-cell

- **4-cell formation**

The optimal solution for the 4 -cell formation is shown below in figure 5, and solved using the algorithm developed in Mukattash and Tahboub (2004).

		PARTS										
		3	7	1	2	6	9	5	8	10	4	11
MACHINES	1	1	1	1	0	0	0	0	0	0	0	1
	5	1	1	0	0	0	0	0	0	0	0	0
	2	0	0	1	1	1	0	0	0	0	0	0
	3	0	0	0	1	1	1	0	0	0	0	0
	4	0	0	0	0	0	0	1	0	1	1	0
	7	0	0	0	0	0	0	1	1	1	0	0
	6	1	0	0	0	0	0	0	0	0	1	1

Fig (5): Optimal solution for the 4-cell

- **5-cell formation**

The optimal solution for the -cell formation is shown below in Figure 6, and solved using the algorithm developed in Mukattash *et al* (2012).

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		PARTS										
		3	7	1	2	6	9	5	8	10	4	11
MACHINES	1	1	1	1	0	0	0	0	0	0	0	1
	5	1	1	0	0	0	0	0	0	0	0	0
	2	0	0	1	1	1	0	0	0	0	0	0
	3	0	0	0	1	1	1	0	0	0	0	0
	4	0	0	0	0	0	0	1	0	1	1	0
	7	0	0	0	0	0	0	1	1	1	0	0
	6	1	0	0	0	0	0	0	0	0	1	1

Fig (6): Optimal solution for the 5-cell

4. Sensitivity Analysis of Different Evaluation Measures

To analyze the behavior of the above measures all the optimal solutions (Figure 2 to 6) will be tested. The following table summarizes the results.

Table 1: Evaluation of different measures

# of cells	Voids (v)	Exceptions (e)	v+e	Sparsity (B)	Total number of operations in the MP matrix	# of operations inside the cells	*Grouping Index* (γ),	Grouping Efficacy (τ)	Grouping capability index (GCI)
2-cell 1st solution	20	2	22	39	21	19	0.56	0.45	0.904
2-cell 2nd solution	19	3	22	37	21	18	0.542	0.45	0.85
3-cell	6	2	8	25	21	19	0.724	0.73	0.904
4-cell	3	4	7	20	21	17	0.7022	0.71	0.81
5-cell	1	6	7	16	21	15	0.641	0.68	0.71

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From table 1 it is clear that the 2-cell solution with the same sum of voids and exceptions has the same efficacy (0.45) regardless of decreasing the sparsity and number of operations inside the cells. In the two cell-formations, grouping index and grouping capability index are decreased as number of voids decrease.
The main principle of cell formation is to form cells with a minimum sum of voids and/ or exceptions (optimality). Based on this principle, the designer will choose the system with lowest (e+v), which is cell-4 or cell-5. But the main objective of grouping measures is to choose the cell with highest quality (efficiency). According to grouping measures, the designer will choose as follows: For τ , he will choose the 3-cell, but the 3-cell has higher value of (e+v) than the 4-cell and the 5-cell. For **GCI,** he will choose the 2-cell (second solution) or the 3-cell; but the 2-cell has the highest value of (e+v) among all the distributions. For γ , he will choose the 3-cell, but the 3-cell has a higher value of (e+v) than the 4-cell and the 5-cell. Moreover, it is noted that the sparsity of the cells and number of operations inside the cells have no direct impact on these grouping measures.

4.1 Illustration 2

The case study contains 24 machines and 40, taken from Nair & Narendran (1996). The following table summarizes the results.

Table 2: Evaluation of different measures

# of cells	Voids (v)	Exceptions (e)	v+e	Sparsity (B)	Total number of operations in the MP matrix	# of operations inside the cells	*Grouping Index* *(γ),*	Grouping Efficacy (τ)	Grouping capability index (GCI)
7	*7*	*19*	*26*	*131*	*143*	*124*	*0.8195*	*0.8267*	*0.867*
7	*19*	*7*	*26*	*131*	*119*	*112*	*0.8195*	*0.8116*	*0.940*
7	20	30	50	131	*141*	111	0.6795	0.6894	0.787
7	30	20	50	131	121	101	0.6795	0.6689	0.835

Table 2, shows that the number of cells, sparsity and sum of voids and exceptions are constant for both cells. Based on these measures the designer cannot choose the optimal or the best distribution between the two cells (v+e=26), since the three grouping measures give different conflict evaluations. For Grouping Index (γ), there is no difference between the two cells. For Grouping Efficacy (τ), the designer can choose the first cell (minimum voids). For grouping capability index (GCI), the designer can choose the second cell (minimum exceptions). In other words the designer can ignore these measures and make his decision based on the shop floor's constraints (based on his wish).We can conclude the same thing for the other two cells (v+e=50).

5. Discussion and Concluding Remarks

From the above discussion, the following can be inferred. In the first case where the total number of operations in the solved matrix are constant for all cells, it is noticed that the highest value of the performance measure (with highest efficiency) may not lead to choose the optimal system (with minimum sum of voids and exceptions) or to compare between two alternative optimal manufacturing systems. We can conclude that there is a contradiction between cells formed based on optimality (minimum sum of voids and/ or exceptions) or based on highest quality (highest efficiency). In these cases the only way to compare and choose between theses manufacturing systems, is to compare with reference to the optimality (minimum sum of voids and exceptions), since on the shop floor optimality is more important than efficiency, and in this case study the decision is left to the designer to choose between the 4-cell and the 5-cell. Moreover, it is noted that the sparsity of the cells and number of operations inside the cells have no direct impact on these grouping measures.
In the second case (Table 2) where the number of cells, sparsity and sum of voids and exceptions are constant for both cells, it is clear that the designer cannot choose the optimal or the best distribution between the two cells (v+e=26), since the three grouping measures give different conflict evaluations.

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From the above discussion it can be concluded that, the impact of grouping measures in cellular manufacturing systems can be summarized as follows:

1. The case where all distributions of the main system are optimal and the total number of operations in the Machine-Part matrix is constant
   In this case the main system is distributed to different systems having different number of cells. The designer has to choose the optimal distribution among all these optimal solutions. In this case grouping efficiency measures, may not lead to choosing the optimal solution since the highest value of evaluation is different than the optimal distribution (minimum sum of voids and exceptions). In this case the right decision will be based on optimality rather than efficiency. Also, the case where alternative optimal solution exists, grouping measures, will make the designer more confused about the right decision. In this case the decision will be taken based on minimum exceptions or voids.

2. The case where number of cells are constant for different distributions. In this case the sparsity and sum of voids and exceptions are constant. The selection of one of the two systems may not depend on grouping efficiency measures, since they may give different conflict evaluations of the both distributions. In this case the designer will choose the distribution based on the shop floor's constraints.

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