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Grouping Cell Indicator: A Modified Cell Formation Grouping Measure

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Abstract: A number of grouping measures have been developed in the literature to evaluate the efficiency of block diagonal forms in cell formation. The commonly known grouping efficiency measures will be discussed in this paper. The most used measure in the literature is grouping efficacy. These measures do not have the ability to distinguish between two or more alternative optimal manufacturing systems with similar voids and exceptions. Moreover, none of these measures can evaluate the block systems and sub-systems at the same time. In this paper a modified grouping measure, called the Grouping Cell Indicator, is proposed to overcome the above limitations. The main features of the proposed Grouping Cell Indicator are: First, Grouping Cell Indicator can distinguish between two or more alternative optimal cell formations with similar voids and exceptions. Second, Cell Indicator (α) reflects the quality of every cell in the formed problem, which will lead to compare between ill- structured cell and other types of cells. Third, Grouping Cell Indicator can be used to evaluate the efficiency of block diagonal forms in cell formation where optimal solution does not exist and the results of using this measure were very close to grouping efficacy. Forth, grouping cell indicator provides the designer with the opportunity of choosing between alternative cell formation solutions. Finally, the proposed measure is tested and the result demonstrate the ability of this measure to distinguish between alternative optimal systems, compared with other measures and demonstrate the ability to compare between different types of cells.

Key words: Cell Formation · Grouping Measures · Grouping Cell Indicator · Cell Indicator · Optimal Solution · Alternative Optimal Solution · Ill-Structured Cell · Perfect- Structured Cell

INTRODUCTION

Group technology deals with the formation of the machine groups and part families that make up the cells at a cellular manufacturing facility. Specifically, the machine-part cell formation problem addresses the issues surrounding the creation of part families based on component processing requirements and the identification of machine groups based on their ability to process specific part families (Brown and Sumicherast, 2001). Cellular manufacturing (CM) is an important application of group technology (GT) in which sets (families) of parts are produced on a group of various machines, which are physical close together and can entirely process a family of parts. The identification of part families and machine groups in the design of cellular manufacturing systems is commonly referred to as cell design/formation [1]. Cellular manufacturing provides an excellent production infrastructure that facilities the incorporation of basic elements for successful implementation of modern technologies, such as Just-in-Time (JIT), Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Flexible Manufacturing Systems (FMS), Computer Integrated Manufacturing (CIM) [2]. Algorithms that aim at forming the part families and machine cells essentially try to rearrange the rows and columns of part/machine incidence matrix to get a block diagonal form. The ideal situation is one in which all the ones are in the diagonal

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blocks and all the zeros are in the off-diagonal blocks. However, the ideal case seldom occurs in a real shop floor problem [3]. The structure of the final machine-component matrix significantly affects the effectiveness of the corresponding cellular manufacturing system [4]. For this reason the choice of grouping methodology must be based on criteria that can indicate the goodness of a grouping solution. Hence, a number of grouping measures have been developed to evaluate the efficiency of block diagonal forms. The commonly known grouping efficiency measures in the literature are the Grouping efficiency (γ) Chandrasekhoran and Rajogopalan [5], Grouping efficacy (τ) Kumar and Chandrasekhoran [6], Grouping capability index (GCI) Hsu [7], Global efficiency (GLE): Harhalakis *et al* [8], Grouping measure Miltenburg and Zhang [9]., Grouping Index (γ) Nair and Narendran [10], Weighted Grouping Efficiency Sarkar and Khan [11] and Double weighted grouping efficiency Sarkar [12]. Kichun Lee and Kwang-Il Ahn [13] pointed out that, grouping efficacy is used as a standard measure for evaluating solutions based on a binary part-machine matrix, which does not consider ordinal data. For other measures that are available in the literature see Sarker and Mondal [14], Sarker and Khan (2001) and Sarker [12], Kellie *et al* [15] and Kichun Lee and Kwang-Il Ahn [13].

All the above grouping measures do not have the ability to distinguish between two or more alternative manufacturing systems with similar voids and exceptions. Also, these measures do not have the ability to determine (or quantify) the quality of individual cells inside the matrix. Moreover, none of these measures can evaluate the block systems and sub-systems at the same time.

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: A zero element appearing in a diagonal block.

Exceptional Element (Or Exception): 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)

Optimal Solution: A system that contains minimum sum of voids and exceptions in the solved matrix

Alternative Optimal Solution: Two or more systems having with similar voids and exceptions in the solved matrix Mukattash [16].

This paper introduces a modified measure called Grouping Cell Indicator (λ), which is considered to be more accurate to determine the efficiency of a block diagonal form for developing cellular manufacturing systems. Moreover, (λ) measure is considered to be more effective since, the efficiency of individual cells can be determined concurrently with evaluation the efficiency of the block diagonal form. Unlike the existing measures in the literature (λ) measure can distinguish between two or more alternative manufacturing systems with similar voids and exceptions. The rest of this paper is organized as follows: in Section 2 overview of grouping measures. Testing these grouping measures will be introduced in section 3. Implementation of the proposed measure, cell indicator and the computational results are described in Section 4. Finally, conclusion is given in Section 5.

Commonly Known Grouping Efficiency Measures: The most available used measures for goodness of cells are shown and discussed in the following sub-sections:

Grouping Efficiency(γ), Chandrasekhoran and Rajogopalan, [5]. The main drawbacks of GE have been exposed already in earlier studies (for more details see Kumar and Chandrasekharan, [6], Sarker and Mondal [14], Sarker and Khan (2001) and Sarker [11].

It is defined as:

$$\eta = q\mu_1 + (1-q)\mu_2, \qquad 0 \le q \le 1$$

where

$$\mu_1 = \frac{e_d}{e_d + e_v}$$

$$\mu_2 = \frac{mn - (e_d + e_v + e_0)}{mn - (e_d + e_v)}$$

and

e_d=total number of operations in the MP matrix

e_0=number of exceptions

e_v=number of voids

q=weighted factor

m= total number of parts in the matrix

n = total number of machines in the matrix

Grouping Efficacy (τ): Kumar and Chandrasekharan (1990), To overcome the problems of (γ), grouping efficacy has been introduced.
Grouping efficacy (τ) is defined as:

$$\tau = \frac{1-\Psi}{1+\varphi}$$

where:

$$\Psi = \frac{\textit{Number} \text{ of exceptional elements}}{\text{Total number of operations in the MP matrix}}$$

$$\varphi = \frac{\textit{Number} \text{ of voids in the diagonal blocks}}{\textit{Total} \text{ number of operations in the MP marix}}$$

τ can be written as:

$$\tau = \frac{e - e_0}{e + e_v}$$

where
e: total number of operations in the MP matrix
e_0: number of exceptions
e_v: number of voids

Grouping Index (GI): Nair and Narendran, (1996): GI is derived from the modified grouping efficacy by introducing a correction factor.

$$GI = \frac{1 - \frac{qe_v + (1-q)(e_0 - A)}{B}}{1 + \frac{qe_v + (1-q)(e_0 - A)}{B}}$$

where A = 0 for $e_0 \leq B$ and A = e_0-B for e_0 greater than B.

γ can be written as follows :

$$GI = \frac{1-\alpha}{1+\alpha}, where \qquad \alpha = \frac{qe_v + (1-q)(e_0 - A)}{B}$$

and A is a crrection factor and B is the sparsity of the solved matrix.

Grouping capability index (GCI), Hsu (1990), does not take any consideration to the number of voids in the matrix. It is defined as:

$$GCI = 1 - \frac{e_o}{e}$$

where:
e_o: number of exceptional elements in the machine-component matrix.
e: total number of one entries in the machine-component matrix.

Global Efficiency (GLE): Harhalakis *et al* (1990), does not take any consideration to the number of voids in the matrix.

It is defined as: the ratio of the total number of operations that are performed within the suggested cells to the total number of operations in the system.

$$\text{Global efficiency} = \frac{\sum_{i=1}^{n} S_i}{\sum_{i=1}^{n} r_i}$$

where:
s_i: is the number of operations in the routing r_i that are performed in the cell corresponding to part p_i.
r_i: total number of operations in the MP matrix

Weighted grouping efficacy, Ng (1993):

$$\gamma = \frac{q(e - e_0)}{q(e + e_v - e_0) + (1 - q)e_0}$$

where
e: total number of operations in the MP matrix
e_0: number of exceptions
e_v: number of voids
q:weighted factor

Weighted Grouping Efficiency, Sarkar and Khan (2001):

$$\eta_q = \frac{qe_1 + (1 - q)e_v}{e_1 + e_v} - \frac{(1 - q)e_0}{e_1 + e_0}$$

where
q = a weighting factor for exeptional and block - diagonal elements;
e_1 = number of ones in the diagonal blocks of a solved machine - part incidence matrix;
e_v = number of voids in the diagonal blocks in the solved matrix; and
e_0 = number of exceptional (off - diagonal) elements in the solved matrix.

Double Weighted Grouping Efficiency, Sarkar (2001):

$$\eta_Q = \frac{qe_1 + (1 - q)e_v}{e_1 + e_v} \cdot \frac{qe_1 + (1 - q)e_0}{e_1 + e_0}$$

where
q = a weighting factor for exeptional and block - diagonal elements;
e_1 = number of ones in the diagonal blocks of a solved machine - part incidence matrix;
e_v = number of voids in the diagonal blocks in the solved matrix; and
e_0 = number of exceptional (off - diagonal) elements in the solved matrix.

Grouping Measure, Miltenburg and Zhang (1991):

$$\eta_g = \frac{e_1}{(e_1 + e_v)} - \frac{e_0}{e}$$

where
e_1 = number of ones in the diagonal blocks of a solved machine - part incidence matrix;
e_v = number of voids in the diagonal blocks in the solved matrix; and
e_0 = number of exceptional (off - diagonal) elements in the solved matrix.
e : total number of operation in MP matrix

Percentage of Exceptional Elements (PE): Chandrasekharan and Rajagopalan, (1986):

$$PE = \frac{EE}{UE} \times 100$$

where
PE: defined as the number of exceptional elements to the number of unity elements in the incidence matrix;
UE: denotes the number of unity elements in the incidence matrix (total number of operations in the data matrix).
EE: Total number of exceptional elements

Sensitivity Analysis of Different Evaluation Measures: Some of the above mathematical measures showed that there are strong mathematical relations between them. A numerical problem is solved below in order to study the behavior of these measures with existing of alternative optimal systems.

Problem 3.1: Consider the system of Table 1 that contains 12-machines and 12-parts call it (problem 3.1).

Table 1: Problem 3.1

Machine	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	0	1	0	1	0	0	0	0	0	0
2	0	0	1	0	0	0	0	0	1	1	0	0
3	0	1	0	0	0	1	0	0	0	0	0	1
4	1	0	0	0	1	0	0	1	0	0	1	0
5	1	1	0	1	0	0	0	0	0	0	0	0
6	0	0	1	0	0	0	0	0	1	1	0	1
7	0	0	1	0	0	0	0	0	1	1	0	1
8	0	1	0	1	0	0	0	0	0	0	0	1
9	1	0	1	0	0	0	1	1	0	0	0	1
10	0	1	0	1	1	0	1	0	0	0	0	0
11	0	0	1	0	0	0	0	0	1	1	0	0
12	0	0	0	0	1	0	1	1	0	0	1	0

The following tables are three different optimal solutions for the above problem. All the solutions have a number of exceptions equal to eight and a number of voids equal to twelve. Moreover, the number of machines and the number of parts within the cells are different for the three solutions.

Table 2: Solution 1

Machines	1	2	4	6	7	5	8	11	3	9	10	12
1	1	1	1	1	0	0	0	0	0	0	0	0
3	0	1	0	1	0	0	0	0	0	0	0	1
5	1	1	1	0	0	0	0	0	0	0	0	0
8	0	1	1	0	0	0	0	0	0	0	0	1
9	1	0	0	0	1	0	1	0	1	0	0	1
10	0	1	1	0	1	1	0	0	0	0	0	0
12	0	0	0	0	1	1	1	1	0	0	0	0
4	1	0	0	0	0	1	1	1	0	0	0	0
2	0	0	0	0	0	0	0	0	1	1	1	0
6	0	0	0	0	0	0	0	0	1	1	1	1
7	0	0	0	0	0	0	0	0	1	1	1	1
11	0	0	0	0	0	0	0	0	1	1	1	0

Table 3: Solution 2

Machine	1	2	4	6	7	5	8	11	3	9	10	12
1	1	1	1	1	0	0	0	0	0	0	0	0
3	0	1	0	1	0	0	0	0	0	0	0	1
5	1	1	1	0	0	0	0	0	0	0	0	0
8	0	1	1	0	0	0	0	0	0	0	0	1
10	0	1	1	0	1	1	0	0	0	0	0	0
12	0	0	0	0	1	1	1	1	0	0	0	0
4	1	0	0	0	0	1	1	1	0	0	0	0
2	0	0	0	0	0	0	0	0	1	1	1	0
6	0	0	0	0	0	0	0	0	1	1	1	1
7	0	0	0	0	0	0	0	0	1	1	1	1
11	0	0	0	0	0	0	0	0	1	1	1	0
9	1	0	0	0	1	0	1	0	1	0	0	1

Table 4: Solution 3

Machines	2	4	6	12	1	7	5	8	11	3	9	10
1	1	1	1	0	1	0	0	0	0	0	0	0
3	1	0	1	1	0	0	0	0	0	0	0	0
5	1	1	0	0	1	0	0	0	0	0	0	0
8	1	1	0	1	0	0	0	0	0	0	0	0
9	0	0	0	1	1	1	0	1	0	1	0	0
10	1	1	0	0	0	1	1	0	0	0	0	0
12	0	0	0	0	0	1	1	1	1	0	0	0
4	0	0	0	0	1	0	1	1	1	0	0	0
2	0	0	0	0	0	0	0	0	0	1	1	1
6	0	0	0	1	0	0	0	0	0	1	1	1
7	0	0	0	1	0	0	0	0	0	1	1	1
11	0	0	0	0	0	0	0	0	0	1	1	1

Applying the different measures of goodness discussed earlier to evaluate the quality of the above different solutions, the following table (Table 5) was obtained.

Table 5: Evaluation of different measures for problem 3.1

Table	# machines in 1st cell	# machines in 2nd cell	# machines in 3rd cell	# parts in 1st cell	# parts in 2nd cell	# parts in 3rd cell	e+v	γ	τ	GI	GCI	GLE	γ	μ_q	μ_Q	μ_g	PE
2	4	4	4	4	4	4	20	.83	.64	.65	.81	.81	.64	0.41	0.25	0.56	18.1%
3	5	2	5	4	4	4	20	.83	.64	.65	.81	.81	.64	0.41	0.25	0.56	18.1%
4	4	4	4	4	5	3	20	.83	.64	.65	.81	.81	.64	0.41	0.25	0.56	18.1%

From Table 5, it is clear that all grouping measures give the same results for all the three solutions. Since the three solutions have different cell sizes, then these measures do not give consideration to the cell size. Moreover, the designer does not have the flexibility to choose one of these solutions since they all have the same quality of goodness. Furthermore the quality of each cell within the system cannot be determined by using the above measures. For the above reasons it is appropriate that a measure that can take into consideration all the above limitations of the existing measures be developed.

Proposed Measure

Grouping Cell Indicator: A proposed modified grouping measure, (*Grouping Cell Indicator* □) is based on grouping cell index (Mukattash 2003).

Grouping Cell Index (λ) can be defined as follows:

$$\lambda = \frac{1}{n+m}\sum_{j=1}^{p}\frac{k_j(n_j+m_j)}{k_j+v_j+e_j}$$

$$\lambda = \frac{1}{n+m}\left[\frac{k_1(n_1+m_1)}{k_1+v_1+e_1}+\frac{k_2(n_2+m_2)}{k_2+v_2+e_2}+\ldots+\frac{k_p(n_p+m_p)}{k_p+v_p+e_p}\right]$$

where,

m= total number of parts in the matrix

n = total number of machines in the matrix

m_i = number of parts in the ith diagonal block [ith cell]

n_i = number of machines in the ith diagonal block [ith cell]

v_i = number of voids in the ith diagonal block

e_i = number of exceptional elements in the ith off-diagonal block

k_i = number of operations in the ith diagonal block [total number of ones in the ith cell]

p = total number of diagonal blocks [total number of cells in the matrix]

k_i+e_i = total number of operations in the matrix

Grouping measure can be rewritten as :

$$\lambda = \frac{1}{n+m}\left[\frac{k_1(n_1+m_1)}{k_1(1+\frac{v_1+e_1}{k_1})} + \frac{k_2(n_2+m_2)}{k_2(1+\frac{v_2+e_2}{k_2})} + \ldots\ldots + \frac{k_p(n_p+m_p)}{k_p(1+\frac{v_2+e_p}{k_p})}\right]$$

$$let\ \alpha_1 = \frac{v_1+e_1}{k_1},\ \ \alpha_2 = \frac{v_2+e_2}{k_2}\ \ \text{and}\ \ \alpha_\text{p} = \frac{v_p+e_p}{k_p}$$

where α_1 = cell indicator of the first cell, α_2 = cell indicator of the second cell and α_p = cell indicator of the pth cell

$$then\ \lambda = \frac{n_1+m_1}{n+m}\times\frac{1}{1+\alpha_1} + \frac{n_2+m_2}{n+m}\times\frac{1}{1+\alpha_2} + \frac{n_p+m_p}{n+m}\times\frac{1}{1+\alpha_p}$$

$$Also\ \text{let}\ \beta_1 = \frac{n_1+m_1}{n+m},\ \beta_2 = \frac{n_2+m_2}{n+m}\ \text{and}\ \beta_\text{p} = \frac{n_p+m_p}{n+m}$$

then λ can be written as :

$$\lambda = \frac{\beta_1}{1+\alpha_1} + \frac{\beta_2}{1+\alpha_2} + \ldots\ldots + \frac{\beta_p}{1+\alpha_p}$$

$$\lambda = \sum_{j=1}^{p}\frac{\beta_j}{1+\alpha_j}$$

Properties of Grouping Cell Indicator Function:

1. Non negativity: All the elements of grouping cell indicator are positive.
2. Physical meaning of extremes:

a. When all the ones in the perfect diagonal block are outside the diagonal block [condition of zero efficiency], then $\lambda = 0$ because $k_1 = k_2 = k_p = 0$.

b. For perfect diagonal block [condition of 100% efficiency], then $\lambda=1$ because

$v_1 = v_2 = v_p = 0$ and
$e_1 = e_2 = e_p = 0$
and $(n+m) = (n_1+m_1) + (n_2+m_2) + \ldots + (n_p+m_p)$ then $\lambda = 1$

c. From property 1 and property 2 it is found that $0 \le \lambda \le 1$.

From the definition of Grouping Cell Indicator, it is clear that this measure (Cell Indicator-α) reflects the quality of every cell by taking into consideration the number of operations, voids and exceptions for every sub-system in the solved matrix. Moreover, Grouping Cell Indicator *(□)* takes into consideration in every cell, the number of voids, number of exceptional parts, number of operations in every sub-matrix, number of parts and machines in each cell and number of the whole machines and parts in the system regardless of the size of the matrix. Since Grouping Cell Indicator is the sum of all individual cells, then the designer can discover the quality of each cell which will help him to distinguish between ill- structured cell and other types of cells.

Superiority of Grouping Cell Indicator: This subsection demonstrates the merits of Grouping Cell Indicator by comparing it with the other measures that were discussed in Section 2.

4.3.1 Comparison with other grouping measures in the case of alternative optimal solution

In order to test the modified grouping measure (□), problem 3.1 (Table 1) is evaluated using the Grouping Cell Indicator. Table 6 shows the result of using the proposed measure. The third optimal solution (Table 4) is solved in details using grouping cell indicator.

$$\lambda = \frac{1}{n+m}\left[\frac{k_1(n_1+m_1)}{k_1(1+\frac{v_1+e_1}{k_1})}+\frac{k_2(n_2+m_2)}{k_2(1+\frac{v_2+e_2}{k_2})}+.......+\frac{k_p(n_p+m_p)}{k_p(1+\frac{v_2+e_p}{k_p})}\right]$$

$$\lambda = \frac{1}{24}\left[\frac{11(8)}{11(1+\frac{5+5}{11})}+\frac{13(9)}{13(1+\frac{7+2}{13})}+\frac{12(7)}{12(1+\frac{0+1}{12})}\right]$$

$\lambda = 0.6654$, for the third solution.

from the above formula we can find cell indicator α for all cells.

$$\text{for cell 1, } \alpha_1 = \frac{5+5}{11} = 0.909$$

$$\alpha_2 = \frac{7+2}{13} = 0.692$$

$$\alpha_3 = \frac{0+1}{12} = 0.0833$$

In the same way we find the value of □ for solution 2 and solution 3. Table 6 below summarizes the results while table 9 below summarizes the results of α for all cells of the three solutions.

Table 6: Evaluation using grouping cell indicator measure for problem 3.1

Table	# machines in 1st cell	# machines in 2nd cell	# machines in 3rd cell	# parts in 1st cell	# parts in 2nd cell	# parts in 3rd cell	e+v	□
2	4	4	4	4	4	4	20	0.6458
3	5	2	5	4	4	4	20	0.64
4	4	4	4	4	5	3	20	0.6654

From the above table it is clear that the goodness measures are not the same for each solution which means that Grouping Cell Indicator (□) is sensitive to the following factors, which are also the factors important in the design of manufacturing cells:

i. Number of machines inside the cell.
ii. Number of parts inside the cell
iii. Number of ones inside the cell.
iv. Number of voids inside the cell.
v. Number of exceptional elements
vi. Number of machines and parts of the whole matrix

The superiority of the proposed Grouping Cell Indicator measure (□) is summarized as follows:

- Evaluate the efficiency of block diagonal forms in cell formation with and without alternative optimal solution and at the same time,
- Evaluate the efficiency of each cell in the diagonal blocks of a solved machine-part incidence matrix.

Comparison with Some Commonly Known Grouping Efficiency Measures:

Table 7: Comparison of new proposed measure (□) with some commonly known measures, (q=0.5)

Problem	Source	Problem size n×m	# of cells P	Total # of operations in the MP matrix e	# of exceptions e_0	# of voids e_v	Sparsity B	Grouping Index GI	Weighted Grouping Efficiency η_q	Grouping Efficacy τ	Grouping Cell Indicator □
1	Kusiak and Chow (1987)	7×8	3	13	0	7	20	0.702	0.5	0.65	0.67
2	Chen and Cheng (1995)	6×6	2	15	0	5	20	0.777	0.5	0.75	0.79
3	Chen and Cheng (1995)	6×6	3	15	3	2	14	0.6969	0.4	0.706	0.734
4	Yasuda and Yin (2001)	7×9	2	25	1	8	32	0.75342	0.48	0.727	0.735
5	Yang and Jenn-Hwai Yang (2008)	15×15	4	53	8	9	54	0.728	0.4245	0.7258	0.7201

It is clear from Table 7, that the results of both measures (Grouping Efficacy and Grouping Cell Indicator) are very close for all problems and sometimes close to Grouping Index.

Cell Evaluation: In order to evaluate the quality of each cell, Cell Indicator (α) will be used for this purpose.

Ill- Structured Data: S.J.Chen and C.S.Cheng [17]

Ill-structured data is defined as data set refers to an incidence matrix that contains exceptional elements (EE) (i.e. elements not in the machine/part groups).

Cell Indicator (α): In this paper ill- structured data will be defined as data set refers to sub- matrix that contains exceptional elements (e_0) and voids (e_v).

From the definition of Grouping Cell Indicator, Cell Indicator (α) can be defined as the total sum of voids and exceptions of block-diagonal divided by block-diagonal operations of each cell. From the formula of Grouping Cell Indicator, Cell Indicator (α) is written as:

$$\alpha_j = \frac{v_j + e_j}{k_j}$$

Cell Evaluation Steps:

- Step 1: If $\alpha_j = \frac{v_j + e_j}{k_j}$ = 0, then cell j is called *perfect-structured cell*, which means that the sum of voids and exceptions in sub- system j will be zero.
- Step 2: If $\alpha_j = \frac{v_j + e_j}{k_j}$ □ 0.5, then the cell j is called *acceptable- structured cell*, which means that the number of voids and/or exceptions is little bit low in the sub-system j.
- Step 3: If 0.5 $\leq \frac{v_j + e_j}{k_j}$ □ 1, then the cell j is called *moderate- Structured cell*, which means that the number of voids and/or exceptions is little bit high in the sub-system j.
- Step 4: If $\alpha_j = \frac{v_j + e_j}{k_j} \geq 1$ and then the cell j is called *ill- structured cell*, which means that the number of voids and/or exceptions is very high in the sub-system j.

  It means that as the value of α decrease, the existence of voids and/or exceptions will be less and the quality of the solution of the sub-system will be better.
- Step 5: From the above steps, the designer can take the right decision regarding the ill- structured cell or the moderate- structured cell, either to review or repeat the cell formation in the presence of multiple types of machines which will eliminate the exceptional elements (*Loading exceptional elements to these machines can raise the utilization of bottleneck machines*).Another method for raising the utilization is by making outside sub-contracting to manufacture parts on these machines.

Cell Utilization (CU): Iraj *et al.* (2007): Cell utilization is defined as a number of non –zero elements of block-diagonal divided by block-diagonal matrix size of each cell. Cell Utilization can be written as:

$$CU_k = \frac{\textit{Number} \text{ of Opoerations in cell k}}{\text{Block-diagonal Matrix Size of cell k}}$$

CU doesn't take into consideration the exceptional elements of the formed cells.

Problem 3.1 will be used to compare the relation between Cell Indicator (α) and Cell Utilization (CU) with some grouping measures. The following tables summarize the results.

Table 8: Cell Utilization – problem 3.1

Solution number	Cell 1	Cell 2	Cell 3
Solution 1	0.6875	0.6875	0.875
Solution 2	0.65	0.875	0.8
Solution 3	0.6875	0.65	1

Table 9: Cell Indicator – problem 3.1

Solution number	Cell 1	Cell 2	Cell 3
Solution 1	0.818	0.4545	0.42
Solution 2	0.692	0.714	0.375
Solution 3	0.909	0.692	0.08

From Table 8, cell utilization for Cell 3, solution 3 is 1(100%), while this cell contains 1 exceptional element. Also, cell utilization for Cell 1, solution 2 is 0.65(65%), while this cell contains 2 exceptions and 7 voids. This means that number of voids and/or exceptions do not taken into consideration. While cell indicator for all cells in the three solutions shows that there is no perfect-structured cell and the number of voids and exceptions is depend on the value of cell indicator. For example, solution 3, cell 3, the value of α is equal to 0.08 which means that this cell is acceptable- structured cell, with number of voids equal to zero and number of exceptions equal to one.

The following problems show other comparison between cell utilization and cell indicator.

Problem 4.1: Table 10 includes obtained results of 10 × 10 machine–part matrix from the literature S.J. Chen and C.S. Cheng (1995) using Iraj *et al*. method [18].

Table 10: Solution for problem 4.1

Machines	4	5	9	10	1	2	6	3	7	8
6	1	0	1	0	0	0	0	0	0	0
7	1	1	1	1	0	0	0	0	0	0
8	1	1	1	1	0	0	0	0	0	0
1	0	0	0	0	1	1	1	0	0	0
2	0	0	0	0	1	0	0	0	0	0
3	0	0	0	0	1	0	1	0	0	0
9	1	0	1	0	1	1	1	1	1	0
10	0	0	0	0	1	1	1	1	0	1
4	0	0	0	0	0	0	0	1	1	1
5	0	0	0	0	0	0	0	1	0	1

The results are shown in the following tables.

Table 11: Cell Utilization (CU) – problem 4.1

Problem number	Cell 1	Cell 2	Cell 3
4.1	0.8333	0.80	0.8333

The third cell which contains machines 4 and 5 has one void and four exceptions with utilization equal to 83.33%. It is not logical to have high utilization with the number of voids and exceptions equal to the number of operations and the middle cell has three voids with utilization less than 83.33%. It is clear that the designer can't distinguish between these cells according to cell utilization, since all the three cells have utilization over or equal to 80% and he will consider this percentage is high enough to take his decision. In fact on the shop floor the designer will face many problems, since there are bottleneck machines and parts.

Table 12: Cell Indicator (α) – problem 4.1

Problem number	Cell 1	Cell 2	Cell 3
4.1	0.4	0.25	1

The first and the second cell are acceptable-structured cells, while the third cell is considered as ill-structured cell, since in cell three the number of operations is equal to the sum of voids and exceptions.

Two grouping measures will be used to discuss the relation between cell utilization and cell indicator with these measures. The following table summarizes the results.

Table 13: Evaluation of two measures for problem 4.1

Problem number	Grouping Efficacy τ	Grouping Cell Indicator □
4.1	69.2%	69.5%

Grouping efficacy of this system (problem 4.1) is equal to 69.2% and grouping cell indicator is equal to 69.5%. Both measures show that the efficiency of this system is less than 70%. Cell utilization of individual cells doesn't give any indication about the quality of the system, while Cell Indicator (α) gives a clear picture about the quality of the system. In other words, we can conclude that there is no relationship between the cell utilization and the efficiency of the system[19-25].

Problem 4.2

Table 14 includes obtained results of 10 × 10 machine–part matrix from the literature S.J. Chen and C.S. Cheng (1995) using ART1 method.

Table 14: Solution for problem 4.2

Machines	1	2	6	3	7	8	4	5	9	10
1	1	1	1	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0
3	1	0	1	0	0	0	0	0	0	0
4	0	0	0	1	1	1	0	0	0	0
5	0	0	0	1	0	1	0	0	0	0
10	1	1	1	1	0	1	0	0	0	0
6	0	0	0	0	0	0	1	0	1	0
7	0	0	0	0	0	0	1	1	1	1
8	0	0	0	0	0	0	1	1	1	1
9	1	1	1	1	1	0	1	0	1	0

The following tables summarize the results.

Table 15: Cell Utilization (CU) – problem 4.2

Problem number	Cell 1	Cell 2	Cell 3
4.2	0.6667	0.7778	0.750

Table 16: Cell Indicator (α) – problem 4.2

Problem number	Cell 1	Cell 2	Cell 3
4.2	1.5	0.57	0.333

Table 17: Evaluation of two measures for problem 4.2

Problem number	Grouping Efficacy τ	Grouping Cell Indicator □
4.2	59.5%	61%

Grouping efficacy of this system (problem 4.2) is equal to 59.5% and grouping cell indicator is equal to 61%. Both measures show that the efficiency of this system is around 60%.

It is evident from the previous discussion that cell utilization reflect only the percentage of number of operations inside the cell, regardless the number of exceptions that belong to this cell. For that, the designer needs other measure to determine (or quantify) the quality of individual cells inside the matrix. Cell Indicator (α) is considered an effective measure that reflects the quality of individual cells. Moreover, Grouping Efficacy *(τ),* Kumar and Chandrasekharan(1990) and the proposed measure, Grouping Cell Indicator (□), are considered two effective measures that will support the designer decision regarding the efficiency of the whole system with respect to Cell Indicator (α).

CONCLUSION

The common known grouping measures in the literature were discussed. It was noted that these measures were concerned with the number of voids and number of exceptions and operations of sub-matrix resulting in the cell formation solutions. Thus, these measures had the disadvantages of distinguishes between alternative optimal solutions of the same problem and had disability to determine (or quantify) the quality of individual cells inside the matrix. In this paper, Grouping Cell Indicator (□) measure was introduced to overcome the above problems. It was shown that Grouping Cell Indicator measure can distinguish between alternative optimal solutions by taking the number of machines and parts in each cell into consideration. Also, Cell Indicator (α) measure can be used to find the quality of each cell and based on the value of (α), ill- structured cell can be differentiated from other types of cells. Close results were obtained for both measures grouping efficacy and grouping cell indicator when block diagonal forms in cell formation is evaluated in case where alternative optimal solution does not exist.

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