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Modified Grouping Capability Index: A New Measure for Evaluating of Machine- Component Matrices

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Abstract

Different grouping measures have been used to evaluate block-diagonal forms in cellular manufacturing systems. One of these grouping measures is called Grouping Capability Index (GCI). The drawback of this measure is that the effect of voids on efficiency system was not taken into consideration. In this paper, a new grouping measure called Modified Grouping Capability Index (MGCI) is proposed to avoid these limitations. MGCI is tested against some problems from the literature and the results demonstrate the ability of this measure to be used to determine the efficiency of block-diagonal system with the capability of choosing different values of weighting factor which will give the system designer the flexibility to control the cell size.

Keywords: Cell Formation, Grouping Measures, Cell size, Weighting Factor, Modified Grouping Capability Index;

1. Introduction

Group Technology (GT) is a management philosophy about efficient problem-solving based on the knowledge of groups. It builds on the premise that a single solution can be found to solve a set of problems sharing common concepts, principles and tasks, thus it saves time and effort [1]. 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 identification of part families and machine groups in the design of cellular manufacturing systems is commonly referred to as cell design/formation [2]. The ideal situation is the one in which all the ones are in the diagonal blocks and all the zeros off the diagonal blocks [3]. 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 one’s entries outside the diagonal blocks known as “exceptional elements” [4].

The structure of the final machine-component matrix significantly affects the effectiveness of the corresponding cellular manufacturing system [5]. For this reason, the choice of grouping methodology must be based on criteria that can indicate the goodness of a grouping solution. Hence, several grouping measures have been developed to evaluate the efficiency of block diagonal forms. Some of these measures are; Grouping efficacy (τ) [4], Grouping capability index (GCI) [6], Global efficiency (GLE) [7], Grouping measure [8], Weighted grouping efficacy (ω) [9], Grouping Index (γ) [10], Weighted Grouping Efficiency [11], Double weighted grouping efficiency [12], GT efficacy [13], Modified grouping efficacy [14] and Comprehensive grouping efficacy (GCE) [15]. Some of the well-known measures will be discussed below in section 2. For other measures that are available in the literature see [11, 12, 13, 16 and 17].

Some of the above grouping measures contain weighting factor while others do not contain. The importance of weighting factor is that the user can assign different weights to voids and exceptional elements. The assignment of weighting factor is depending on the importance of voids and exceptions on the shop floor.

This paper introduces a new measure for evaluating Block-diagonal forms in Group Technology (GT) called Modified Grouping Capability Index (MGCI). MGCI is more effective since, the efficiency of block-diagonal system can be determined with ability of choosing different values of weighting factor which gives the system designer the flexibility to control the cell size.

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.

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- 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 [4].
- Sparsity (*Block- diagonal* space): Total number of elements within the diagonal blocks of the solved matrix [11].
- Optimal solution: A system that contains minimum sum of voids and exceptions in the solved matrix.

2. Overview of performance measures

The most available used measures for goodness of cells are shown and discussed in the following section.

2.1. Grouping Efficiency (η): [18]

It is defined as:

$$\text{Grouping Efficiency}=q\eta_1+(1-q)\eta_2 \quad (1)$$

where $\eta_1 = \dfrac{e_d}{\left(\sum_{r=1}^{k} M_r N_r\right)}$ and $\eta_2 = 1 - \dfrac{e_o}{\left(\sum_{r=1}^{k} M_r N_r\right)}$.

e_d=total number of operations in the Machine–Part (MP) matrix

e_0=number of exceptions

e_v=number of voids

q=weighted factor, $0 \le q \le 1$

m= total number of parts in the matrix

n = total number of machines in the matrix

2.2. Machine Utilization (MU):[19]

It is defined as:

$$MU = \frac{N_1}{\sum_{c=1}^{c} m_c n_c}, \quad (2)$$

where

N_1 : total number of 1,s in the diagonal blocks of the machine-part incident matrix
n_c:total number of parts in the cth cell
m_c:total number of machines in the cth cell

2.3. Grouping Efficacy (τ): [4]

Grouping efficacy (τ) is defined as:

$$\tau = \frac{1-\Psi}{1+\phi}, \quad (3)$$

where

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

and

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

$$\tau = \frac{k}{k+v+e_0} \quad (4)$$

k+e: total number of operations in the MP matrix,

k: number of operations in the diagonal block,

e: number of exceptions,

v: number of voids.

2.4. Weighted grouping efficacy (ω): [9]

It is defined as:

$$\omega = \frac{q(e-e_0)}{q(e+e_v-e_0)+(1-q)e_0} \quad (5)$$

where e: total number of operations in the MP matrix

e_0: number of exceptions

e_v: number of voids

q:weighted factor

2.5. Grouping Index (γ):[10]

It is defined as:

$$\gamma = \frac{1-\dfrac{qev+(1-q)(e_0-A)}{B}}{1+\dfrac{qev+(1-q)(e_0-A)}{B}} \quad (6)$$

where

$A=0$ for $e_0 \le B$ and $A = e_0 - B$ for e_0 greater than B

can be written as follows,

$\gamma = \dfrac{1-\alpha}{1+\alpha}$,where $\alpha = \dfrac{qe_v+(1-q)(e_0-A)}{B}$ and

$\gamma = \dfrac{1-\alpha}{1+\alpha}$,where $\alpha = \dfrac{qe_v+(1-q)(e_0-A)}{B}$ and A is a correction factor and B is the sparsity of the solved matrix and e_0 is the number of exceptions, e_v is the number of voids and q is the weighted factor.

2.6. Modified grouping efficacy (τ_2): [10]

It is defined as:

$$\tau_2 = \frac{B-qe_v+(1-q)e_0}{B+qe_v+(1-q)e_0} \quad (7)$$

Where B is the sparsity of the solved matrix, e_0, e_v and q represent, the number of voids, the weighted factor and the number of exceptions, respectively.

2.7. Comprehensive Grouping Efficacy (CGE): [15]

It is defined as:

$$CGE = \frac{B_1}{B}\left[\frac{k_1}{k_1+v_1+e_1}\right] + \frac{B_2}{B}\left[\frac{k_2}{k_2+v_2+e_2}\right] + \ldots + \frac{B_p}{B}\left[\frac{k_p}{k_p+v_p+e_p}\right] \quad (8)$$

where B_1, B_2, B_p and B represent the sparsity of the first, the second and the p^{th} cell in the solved matrix, respectively. Also, B represents the sparsity of the solved matrix, which is defined as the total number of elements within diagonal blocks of the solve matrix. Here B represents the sparsity of the solved matrix and $B_1 = n_1 \times m_1, B_2 = n_2 \times m_2 \text{ and } B_p = n_p \times m_p$.

m = total number of parts in the matrix

n = total number of machines in the matrix

m_p = number of parts in the jth diagonal block [jth cell]

n_p = number of machines in the jth diagonal block [jth cell]

v_p = number of voids in the jth diagonal block

e_p = number of exceptional elements in the jth off-diagonal block

k_p = number of operations in the jth diagonal block

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

3. Critical Analysis of Grouping Capability Index Measure

In this section, a mathematical and critical analysis will be addressed for the Grouping Capability Index Measure (GCI) [6]. GCI can be written as:

$$GCI = 1 - \frac{e_o}{e} \tag{9}$$

e_o: number of exceptional elements in the machine-component matrix.

e: total number of one's entries in the machine-component matrix.

The drawback of this measure is that the voids (v) were not taken into consideration. The elements of GCI measure are the exceptions and the total number of elements in the diagonal blocks. This means that there is no effect of voids on GCI measure, and the exceptional elements will have more effect.

A void indicates that a machine assigned to a cell is not required for the processing of a part in the cell. The exceptional element is created when a part requires processing on a machine that is not available in the allocated cell of the part. Exceptional elements and voids are the first two problems which will face the designer. More details about the implications of voids and exceptional are found in [20].

3.1. Mathematical Properties of Grouping Capability Index function

1. Physical meaning of extremes:
   - When all the ones in the perfect diagonal- block are outside the diagonal block (condition of zero efficiency where e is equal to zero), then GCI=0 because k=0.
   - For perfect diagonal block [condition of 100% efficiency], then GCI =1 because e_0=0 and voids (v) have no effect on perfect diagonal block.
2. Non-negativity: The case of zero efficiency will lead to a negative or very small value of efficiency.
3. From property 1 and property 2 it is found that $0 \le GCI \le 1$.

3.2. Testing the Grouping Capability Index Measure

To analyze GCI measure, a computer programming model has been used to test different case studies from literature. One of these cases contains seven machines and eight parts, and its solution matrix is given below in Table 1. This case study is provided by [21].

Problem 1:

Consider the solution matrix of Table 1, taken from the literature [21].

Applying the different measures of goodness discussed earlier to evaluate the quality of the above solution, the following table (Table 2) was obtained.

From Table 2, GCI has efficiency 100%, despite the solution contains seven voids. While the other measures have taken the voids into considerations, for that the efficiency was between 65% and 82%.

Table 1. Final solution matrix 1 for problem 1

Problem 1		2	3	5	8	1	6	4	7
	1	1	1	1	0	0	0	0	0
	5	0	0	0	1	0	0	0	0
	7	0	1	1	1	0	0	0	0
	2	0	0	0	0	1	1	0	0
	4	0	0	0	0	0	1	0	0
	3	0	0	0	0	0	0	1	1
	6	0	0	0	0	0	0	1	0

Table 2. Evaluation of different measures for problem 1(efficiency of block-diagonal form)(q=0.5)

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	η	τ	γ	ω	τ_2	MU	CGE	GCI
1	3	2	2	4	2	2	7	0.82	0.65	0.70	0.65	0.70	0.65	0.65	1.00

4. The Proposed Measure

To avoid the above limitations of GCI measure, a new measure called Modified Grouping Capability Index (MGCI) will be developed in this section. The new measure can be expressed as:

$$MGCI = 1 - \frac{q_1 e + q_2 v}{k + q_1 e + q_2 v} \quad (10)$$

Equation 10 can be written as:

$$MGCI = \frac{1}{1 + \frac{q_1 e + q_2 v}{k}} \quad (11)$$

$$\text{let } \alpha = \frac{q_1 e + q_2 v}{k} \quad (12)$$

α can be rewritten as:

$$\alpha = q_1(\frac{e}{k}) + q_2(\frac{v}{k}) \quad (13)$$

$$\text{then} \quad MGCI = \frac{1}{1+\alpha} \quad (14)$$

Where,

v = number of voids in the diagonal block
e = number of exceptional elements in the off-diagonal block
k = number of operations in the diagonal block
q_i = weighting factor, $0 \le q_i \le 1$ and $q_1 + q_2 = 1$

4.1. Mathematical Properties of MGCI Function

1. Non-negativity: All the elements of comprehensive grouping measure are positive.
2. Physical meaning of extremes:
   - When all the ones in the perfect diagonal- block are outside the diagonal block [condition of zero efficiency], then $MGCI = 0$ because k=0.
   - For perfect diagonal block [condition of 100% efficiency], then $MGCI = 1$ because v = 0 and e=0.
   - From property 1 and property 2 it is found that $0 \le MGCI \le 1$.
3. Effect of α on MGCI $\frac{dMGCI}{d\alpha} = \frac{-1}{(1+\alpha)^2}$

   As α increases, MGCI decreases.
4. Effect of voids and exceptions on α. From equation 12, the influence of v and e is determined by the value of q (to be assigned by the user). For q=0.5, v and e have identical influence on α.
5. Effect of voids and exceptions on MGCI measure. For q=0.5, v and e have identical influence on MGCI measure.

4.2. Superiority of MGCI Measure

In this section we highlight the merits of $MGCI$ comparing to the other measures. $MGCI$ is a new measure since it can be used to find the efficiency of the main system with full information about the system in the solved matrix with different values of weighting factor which will help the designer to control the cell size. Moreover, equation 13 can be used to find (void density) the total number of voids with respect to the total number of operations inside the cells $(\frac{v}{k})$ and (intensity of exceptions) the total number of exceptions with respect to the total number of operations inside the cells $(\frac{e}{k})$. The importance of knowing $(\frac{v}{k})$ and $(\frac{e}{k})$ is that it gives the user the ability to choose the proper values of q_1 and q_2.

4.3. Testing the proposed grouping measure

To illustrate and test the performance of the proposed measure, we use the same industry problem shown in Table 1. The results are shown in Table 3.

From Table 3, MGCI and other measures have taken the effect of voids into consideration. The superiority of MGCI is that it gives the designer the flexibility to control the cell size since the weighting factor can be assigned with different values to the voids and/ exceptions. The assignment of the weighting factor depends on the importance of voids and exceptions with respect to the designer wish. All the required information regarding the efficiency can be obtained concurrently with different values of weighting factor. The benefit of this information is that it gives the system designer the ability and flexibility to control the cell size. Table 4 below shows the effect of changing the values of weighting factor on the efficiency of the system.

Table 4. Analysis of MGCI measure with different values of q_1 & q_2 (problem 1)

q_1	q_2	MGCI
0.1	0.9	0.673
0.2	0.8	0.698
0.3	0.7	0.726
0.4	0.6	0.755
0.5	0.5	0.787
0.6	0.4	0.822
0.7	0.3	0.861
0.8	0.2	0.903
0.9	0.1	0.948

Table 3. Comparison of MGCI with some commonly known measures, (q=0.5)

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	η	τ	γ	ω	τ_2	MU	GCI	MGCI
1	3	2	2	4	2	2	7	0.82	0.65	0.70	0.65	0.7021	0.65	1.00	0.787

Problem 2:

To analyze MGCI measure another case study will be studied and analyzed. The case contains seven machines and eleven parts and its machine – part matrix is given below in Figure 1. This case study is provided by [22].

The two alternative optimal solutions (2-cells) for this case study are shown below in Figure 2 and 3.

To study the effectiveness of MGCI measure the optimal solutions (Figure 2 and 3) are analyzed and the results are compared with different efficiency measures as shown below in Table 5.

From Table 5, we can notice that the results of GCI measure are inaccurate compared with other well-known efficiency measures. For the first solution, the efficiency is around 90%, while the other measures are less than 63%. The reason behind that is because the effect of number of voids is not taken into consideration as discussed above in section 3.1. Moreover, for the second optimal solution, the efficiency is around 85%, while the other measures are less than 62%.

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

Figure1. machine-part matrix for the numerical example.

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

Figure2. First optimal solution for the 2-cell

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

Figure 3. Second optimal solution for the 2-cell

Table 5. Evaluation of different measures for fig.2 and fig.3

# of cells (p)	# of voids (v)	# of exceptions (e)	v+e	# of operations inside the cells (k)	γ	τ	τ_2	ω	CGE	GCI	MGCI
2-cell 1st solution	20	2	22	19	0.56	0.45	0.6	0.463	0.463	0.904	0.63
2-cell 2nd solution	19	3	22	18	0.542	0.45	0.6	0.45	0.456	0.85	0.62

5. Summary and Concluding Remarks

A new grouping measure called Modified Grouping Capability Index (MGCI) has been proposed in this paper to overcome the limitation of Grouping Capability Index (GCI) measure. This limitation is that the effect of voids in the diagonal block was not taken into consideration. The superiority of MGCI is that all the required information regarding the efficiency can be determined concurrently with different values of weighting factor. Moreover, the weighting factor will help the designer to control the cell size through re-assigning the parts inside the cells or through cell reformation, so as the efficiency of these cells will be increased. Moreover, assigning different values of weighting factor will give the designer the flexibility to avoid some constraints on the shop floor.

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