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A new cell formation model using sequence data and handling cost factors

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Abstract

This study addresses cell formation problem (CFP) using sequence data and new considerations. The most previous researches in the literature have used inter-cell movements for clustering different machines and similar parts in form of cells. Covering this shortcoming, we regard an additional cost of utilizing a machine in an outsider part cell as well as handling cost components. A mathematical model is then presented to solve such a more comprehensive problem in cellular manufacturing system (CMS). Also, two benchmark examples will be solved by the proposed model. Computational results demonstrate that our presented model outperforms of previous ones in regard to covering more realistic features in real word.

Keywords
Cell formation problem (CFP); Inter/Intra-cell movement; Sequence data; Handling cost

1. Introduction
Group technology (GT) can be defined as a manufacturing philosophy identifying similar parts and grouping them together to take the advantage of their similarities in manufacturing and design [1]. Actually, GT is an approach to assign individual machines to a group/cell with an appropriate internal group layout for the production of specific component/part families formed in accordance with the similarity of operations, design, instruction, tools, etc., that are to be performed. GT was proposed by Mitrofanov [2] at first, and then Burbidge [3] who developed methods suitable for hand computation, extended this manufacturing approach. Cellular manufacturing (CM) is one of the primary applications of GT principles to manufacturing. It could be specified as a hybrid system linking the advantages of both the jobbing (flexibility) and mass (efficient flow and high production rate) production approaches [4]. The goal of CM is to reduce setup and flow times and therefore to reduce inventory and market response times [5].

Cell formation problem (CFP) is the first step in designing of cellular manufacturing systems. The main objective of CF is to construct machine cells and part families, and then dispatch part families to machine cells to optimize the chosen performance measures such as inter-cell and intra-cell handling cost, grouping efficiency and exceptional elements [6]. CF approaches and algorithms have been developed in the literature considering various production factors, scenarios and objectives due to importance of CF. In the last three decades of research in CF, researchers have mainly used zero–one machine component incidence matrix as the input data for the problem. Although, of late efforts are being made to use other data structures such as interval data [7] and ordinal data (consisting of sequence of processing), see for instance [8-11]. The major limitations of these approaches lie in the fact that important production factors like operation time, sequence of operations, and lot size of the parts are not accounted for. Sudhakara and Mahapatra [12] have been made an attempt to propose a clustering methodology based on adaptive resonance theory (ART) for addressing these issues.

Using of sequence information can help significantly to the designer. Sequence data determines the order of job processing in a manufacturing setup [10]. The sequence of operation has an impact on the flow of material. An intermediate operation of a part accomplished outside its cell involves two inter-cell transfers while the first or last operation requires one such transfer.

Lee and Chen [13], Wu [14] and Wu and Salvendy [15] considered inter-cell moves, operation sequence and production volume as well as replicate machines. Also, Nair and Narendran [9] and Won and Lee [10] used indices

to account for the operation sequence. It is however required to consider the setup in the case of cell formation with sequence data. Ohta and Nakamura [16] proposed a new cell formation with reduction in setup times between machines assigned to the same cell. Jayaswaly and Adil [11] developed a model and solution methodology for a problem of cell formation so as to minimize the sum of costs of inter-cell moves, machine investment and machine operating costs. Yin and Yasuda [17] took into account the operation sequence in the computation of the similarity index, but it is not used for inter-cell move calculations. Vakharia and Chang [18] considered the objective of minimizing the total cost of inter-cell moves and investment in machines and they accounted for operation sequence, production volume, replicate machines and cell size. Alhourani and Seifoddini [19] introduced a new ordinal production data similarity coefficient based on the sequence of operations and the batch size of the parts. Furthermore, they proposed a new clustering algorithm for machine cell formation.
Most of the cell formation studies have focused on the independence of cells, and the number of inter-cell movements is commonly viewed as an indicator of that (see for instance [7,20,21]). Also from the point of view of material handling, multiple operations in an external cell do not matter, if they are consecutive [7, 22].
In this study, we regard four cost components which are defined as follows:

1. The movement cost of a given part for processing two successive operations in the corresponding part's cell.
2. A movement cost (α) is calculated for a given part which needs two successive operations within an external cell.
3. A movement cost (β) is calculated for a given part which needs two successive operations through the two different cells. In this manner, setup and handling costs are occurred.
4. An additional variable cost (γ) for the machine supposed to process i^{th} operation of a given part is considered, in such a way that regarded machine is not within the cell of the part.

The first two components belong to intra-cell costs whiles the first component actually will result in no additional cost, due to being done within their part's cell. The third component is categorized in the inter-cell costs and finally the last one is construed as a setup cost. The last component may cause to aggregate all parts and machines which have more interdependence to each other in the same cell and vice versa.
In the most of previous studies, number of operations which have been processed outside of their part's cell was calculated (Exceptional Elements), which have not been regarded any differences between successive operations within one or two external cells. This shortcoming motivated us to cover this gap which results in regarding distinct handling costs for two successive operations. In this manner three cost components, α, β and γ have been regarded where α states handling cost of a given part between two facilities in the same but outside of its own cell. β shows handling cost of a given part between two facilities in two different cells. Obviously, β must be considered larger than α, due to emphasizing on processing of two successive operations in the same cell, instead of two different cells. Thereby all consecutive operations gradually will tend to be processed in the same cell.

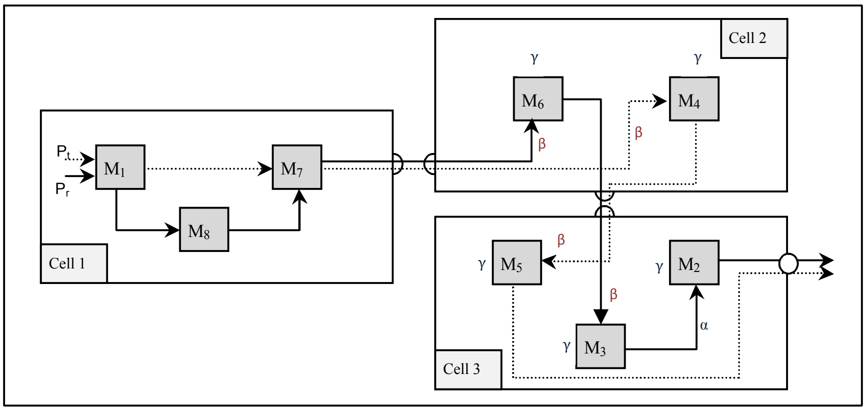

Figure 1: Various types of handling cost components

As illustrated in Figure 1, seven machines are assigned to three cells. Also two parts (P_r and P_t) are allocated to the first cell and their corresponding routes are demonstrated. As the Figure 1 shows and according to described definitions of different types of costs, values α, β and γ are specified clearly. For better understanding, regard P_t in which by meeting machines M_4 and M_5 (M_4-M_5 movement) from cell 2 to cell 3 or M_7 and M_4 (M_7-M_4 movement) from cell 1 to cell 2 will cause a β cost. Also M_1-M_8 movement in cell 1 will cause no additional cost. It's notable

that for machines M_1, M_7 and M_8 assigned to the first cell no extra cost have been considered whereas machines M_4 and M_5 assigned to another cell (cells 2 and 3) will cause additional cost (γ), if any operation of P_r and P_t is performed on them.
To extend these concepts to CFP models, we present a model. Through the replacing the non-linear and schematic constraints by linearlized ones, we achieve an integer linear programming (ILP) model which can be solved by a commercial MIP solver such as CPLEX software. We applied two benchmark examples to validate the model and compare solution quality of proposed approach with previous ones in terms of cell formation factors.
The rest of the paper organized as follows: Section 2 presents the mathematical model. Numerical examples will be illustrated in Section 3. Finally, conclusions are laid out in Section 4.

2. Mathematical model

2.1 Notations

LM_{cell}, UM_{cell}: Lower and upper bound of machines in a cell
LP_{cell}, UP_{cell}: Lower and upper bound of machines in a cell
$MSeq$: The maximum sequence number in part-machine sequence matrix
α, β, γ: The weight factors in objective function
M: A large number

$$z_{pm} = \begin{cases} 1 & \text{if part } p \text{ needs machine } m \\ 0 & \text{otherwise} \end{cases}$$

$$s_{pim} = \begin{cases} 1 & \text{if } i\text{th operation of part } p \text{ is performed on machine } m \\ 0 & \text{otherwise} \end{cases}$$

$$x_{mk} = \begin{cases} 1 & \text{if machine } m \text{ is assigned to cell } k \\ 0 & \text{otherwise} \end{cases}$$

$$y_{pk} = \begin{cases} 1 & \text{if part } p \text{ is assigned to cell } k \\ 0 & \text{otherwise} \end{cases}$$

$$d_{pimk} = \begin{cases} 1 & \text{if } i\text{th operation of part } p \text{ is performed on machine } m \text{ in cell } k \\ 0 & \text{otherwise} \end{cases}$$

$$w_{pik} = \begin{cases} 1 & \text{if } i\text{th operation of part } p \text{ is performed in cell } k \\ 0 & \text{otherwise} \end{cases}$$

$$dd_{pmk} = \begin{cases} 1 & \text{if both part } p \text{ and machine } m \text{ assigned to cell } k \text{ concurrently} \\ 0 & \text{otherwise} \end{cases}$$

2.1 Formulation

$$Min\ Z = \beta \sum_k \sum_p \sum_{i<MSeq} \left(w_{pik}(1 - w_{pi+1k}) \right) + \alpha \sum_k \sum_p \sum_{i<MSeq} \left((1 - y_{pk})(w_{pik} . w_{pi+1k}) \right) + \gamma \sum_p \left(\sum_m z_{pm} - \sum_m \sum_k (z_{pm} - dd_{pmk}) \right) \quad (1)$$

St.

$$d_{pimk} = s_{pim} . x_{mk} \qquad \forall\ m, i, p, k \quad (2)$$

$$w_{pik} = \sum_m d_{pimk} \qquad \forall\ p, i, k \quad (3)$$

$$dd_{mpk} = x_{mk} . y_{pk} \qquad \forall\ p, m, k \quad (4)$$

$$\sum_k x_{mk} = 1 \qquad \forall\ m \quad (5)$$

$$\sum_k y_{pk} = 1 \qquad \forall p \quad (6)$$

$$\sum_m x_{mk} \geq LM_{cell} \qquad \forall k \quad (7)$$

$$\sum_m x_{mk} \leq UM_{cell} \qquad \forall k \quad (8)$$

$$\sum_p y_{pk} \geq LP_{cell} \qquad \forall k \quad (9)$$

$$\sum_p y_{pk} \leq UP_{cell} \qquad \forall k \qquad (10)$$

$$x, y, d, dd, w \in \{0,1\} \qquad (11)$$

The first constraint introduces the objective function which consists of three cost components; inter-cell movements with a β weight, intra-cell movements outside the part cell with α penalty and finally machine usage additional cost (γ) caused outside the part cell. Constraint (2) shows that whether i^{th} operation of the part p on machine m, assigns to cell k or not. Constraint (3) identifies the cell where i^{th} operation of part p is performed. Constraint (4) determines whether part p on machine m is assigned to cell k or not. Equations (5) and (6) ensure that each machine and part separately is assigned to only one cell, respectively. Constraints (7) and (8) together show min and max number of machines in each cell. Also, constraint (9) and (10) together show min and max number of parts in each cell and finally constraint (11) states being binary of variables.

3. Numerical examples

To depict some perspectives on new considerations in CFP and compare the proposed model with previous ones, two benchmark examples used in [7] and [9] will be presented. These examples are solved mathematically by using CPLEX 11.1 software on a laptop with Intel® Core™2Dou/2.8 GH and 4GB RAM. For both examples the additional cost factors are constant and set as following; α=1, β=2 and γ=3.

3.1 Example 1

The initial part-machine matrix with sequence data are shown in Table 1 as stated in [9]. The result of proposed model and what obtained in [9] is the same one presented in Table 2. By applying the Boundary efficiency such that was explained in [9] we have a comparison between new result and previous one. In this example the Boundary efficiency for both results are equal to 80.49%.

Table 1: 8×20 part-machine matrix in [9], (Example 1)

Components	Machines							
	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8
P_1					2	1		
P_2	1		2					
P_3	2	1		5			3	4
P_4		1		2			3	4
P_5					2	1		
P_6		1		2	5		3	4
P_7		4		2			3	1
P_8	1		2					
P_9	1		3			2		
P_{10}				2	3	1		
P_{11}	3		2				1	
P_{12}					1	3	2	
P_{13}	1		2					
P_{14}	1	2	3					
P_{15}					1	2		
P_{16}	1		2					
P_{17}	3		1		2			
P_{18}		2		1			4	3
P_{19}	1		2					
P_{20}		2		1		3	4	5

Table 2: The proposed model result for Example 1

Components	Machines							
	M_1	M_3	M_2	M_4	M_7	M_8	M_5	M_6
P_1							2	1
P_5							2	1
P_{12}					2		1	3
P_{15}							1	2
P_{10}				2			3	1
P_3	2		1	5	3	4		
P_4			1	2	3	4		
P_6			1	2	3	4	5	
P_7			4	2	3	1		
P_{18}			2	1	4	3		
P_{20}			2	1	4	5		3
P_{17}	3	1					2	
P_9	1	3						2
P_{14}	1	3	2					
P_2	1	2						
P_8	1	2						
P_{11}	3	2			1			
P_{13}	1	2						
P_{16}	1	2						
P_{19}	1	2						

3.2 Example 2

In second example, the part-machine matrix used in [7] and [9] is considered and presented in Table 3. Result of proposed model is illustrated in Table 4. Here, the result of proposed model differs from results mentioned in [7] and [9].

Table 3: 20×20 part-machine matrix used in Harhalakis et al. [7], (Example 2)

Components	Machines																			
	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}	M_{11}	M_{12}	M_{13}	M_{14}	M_{15}	M_{16}	M_{17}	M_{18}	M_{19}	M_{20}
P_1	2								3			1						4		5
P_2		2	3								1									
P_3								1											3	2
P_4		3	1							4	2									
P_5				1		3	4								2					
P_6					5						1			2		3	4			
P_7					1											2	3			
P_8				5			3		4				2		1					
P_9	4								2		3	5						1		
P_{10}								3											1	2
P_{11}			3					1						2						
P_{12}	5				3				1			4						2		
P_{13}						1	2								3		4			
P_{14}	3	4						1		2										
P_{15}													1	2		3	4			
P_{16}						3	2								1				4	
P_{17}	2								1			3								
P_{18}								1		4									2	3
P_{19}		2	1		4						3									
P_{20}	3									2		4						1		

Table 4: The proposed approach solution for Example 2

Components	Machines																			
	M_5	M_{14}	M_{16}	M_{17}	M_8	M_{19}	M_{20}	M_1	M_9	M_{10}	M_{12}	M_{18}	M_4	M_6	M_7	M_{13}	M_{15}	M_2	M_3	M_{11}
P_6	5	2	3	4																1
P_7	1		2	3																
P_{11}		2			1														3	
P_{15}		2	3	4												1				
P_3					1	3	2													
P_{10}					3	1	2													
P_{18}					1	2	3			4										
P_1							5	2	3		1	4								
P_9								4	2		5	1								3
P_{12}	3							5	1		4	2								
P_{14}					1			3		2								4		
P_{17}								2	1		3									
P_{20}								3		2	4	1								
P_5													1	3	4		2			
P_8									4				5		3	2	1			
P_{13}				4										1	2		3			
P_{16}						4								3	2		1			
P_2																		2	3	1
P_4										4								3	1	2
P_{19}	4																	2	1	3

The Boundary efficiencies for this example based on approaches presented in [7] and [9] are 69.61% and 72% respectively, whereas this comparison index for the model proposed in this paper is better and equal to 74%. Despite existing of this fact that by applying this comparison index, we get better results, but this index is not appropriate enough and it does not cover all the industrial factors in CMS. The suitable characteristics of the proposed model may be more noticeable, if a more appropriate index could be designed.

4. Conclusion

In this paper we proposed a mathematical model for CFP consisting of new components of handling costs which hadn't been regarded by previous researches, i.e. regarding three different types of handling cost factors. For proving our model validation, we used two benchmark examples. Computational results showed higher quality of our outcomes toward previous studies.

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