Cell Forming and Cell Balancing of Virtual Cellular Manufacturing Systems with Alternative Processing Routes Using Genetic Algorithm

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Abstract

Cellular manufacturing (CM) is one of the most important subfields in the design of manufacturing systems. As a recently emerged field of study and practice, virtual cellular manufacturing (VCM) is of enormous importance as one of the types of CM . One kind of VCM problems is VCM with alternative processing routes from which the route for processing each part should be selected. In this study, a bi-objective mathematical programming model is designed in order to obtain optimal routing of parts, the layout of machines and the assignment of cells to locations while minimizing the production costs and balancing the cell loads. The proposed mathematical model is solved by multi-choice goal programming (MCGP). Since CM models are NP-Hard, a genetic algorithm (GA) is utilized to solve the model for large-sized problem instances and the results obtained from both methods are compared. Finally, a conclusion is reached and some suggestions for future works are offered.

Keywords: Virtual Cellular Manufacturing, Mathematical Programming, Multi-Choice Goal Programming, Genetic Algorithm.

1. Introduction

The introduction is composed of two parts: the first part is dedicated to a brief description of group technology (GT) and cellular manufacturing systems (CMS) as well as a presentation of some previous studies in this field. The second part focuses on VCM, related concepts and the previously published studies in this field.

1.1. *Group technology and cellular manufacturing*

Industries always try to maximize their productivity; therefore, in situations where there are many products with low production volumes; GT is a solution for the problem. GT is proposed for maintaining the flexibility of a Job Shop manufacturing and the efficiency of Flow Shop manufacturing. The philosophy of GT is based on grouping similar parts into groups which need similar production processes. In the literature on manufacturing, the groups of parts are called part-families and the group of similar machines are called machine-cells.CM is based on the principles of GT, which seek to take full advantage of the similarity between parts through standardization and common processing. CM leads to setup reduction and provides the workers with the tools to operate multiple processes and to be multifunctional. It makes improvements in quality, reduces the waste, and simplifies machine maintenance. CM has helped firms to make significant improvements in throughput time performance (Isaand Tsuru, 2002; Waterson et al., 1999; Wemmerlov and Johnson, 1997; Wemmerlov and Hyer, 1989). This allows workers to easily self-balance within the cell while reducing lead times, resulting in the ability for companies to manufacture high quality products at a low cost, on time, and in a flexible way (Black, 1991).A detailed survey of studies and approaches was carried out by Papaioannou and Wilson (2010) and Paydar and Saidi-Mehrabad (2013).

1.2. *Virtual cellular manufacturing*

VCM is one of the subfields of CM in which there is no physical separator for dividing cells. VCM Systems (VCMS) are used when it is not possible to use CMS because of technical or financial perspective. VCMS aims to reduce setup times by grouping similar jobs in

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s: Index set of operations of part type i in route $r\,(s = 1,2,3,\ldots,S_{r_i})$

j: Index set of machine types $(j = 1,2,3,\ldots,M)$

u: Index set of locations $(u = 1,2,3,\ldots,U)$

k: Index set of cells $(k = 1,2,3,\ldots,C)$

2.3. Parameters

γ_i^{inter} : Material handling cost between cells per part type i

α_j : Maintenance and overhead cost of machine type j

β_j : Operating cost for machine type j per unit of time

ϕ_{ir} : Setup cost for route r of part i

λ_{irsj} : Processing time of sequence s of part type i along route r with machine j

T_j : Available time for machine type j

D_i : Demand for part type i

L_k : The lower bound of number of machines in cell k

$d_{uu'}$: Distance between location u and u'

a_{irsj} : 1 If operation s of part type i along r must be processed on machine type j; 0 Otherwise

A: A large positive number

2.4. Decision Variables

X_{irsjuk} : 1 If operation s of part type i along route r is processed with machine type j located in location u is assigned in cell k; 0 Otherwise

Z_{juk} :1 If machine type j is located in location u which is placed in cell k; 0 Otherwise.

R_{ir} :1 If route r is set up to produce part type i; 0 Otherwise.

Minimize

$$Z_1 = \sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}-1}\sum_{j=1}^{M}\sum_{j'=1}^{M}\sum_{u=1}^{U}\sum_{\substack{u'=1\\u'\neq u}}^{U}\sum_{k=1}^{C}\sum_{\substack{k'=1\\k'\neq k}}^{C}\gamma_i^{inter}D_i d_{uu'}X_{irsjuk}X_{irs+1j'u'k'} \quad (1)$$

$$+\sum_{j=1}^{M}\sum_{u=1}^{U}\sum_{k=1}^{C}\alpha_j Z_{juk} \quad (2)$$

$$+\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}}\sum_{j=1}^{M}\sum_{u=1}^{U}\sum_{k=1}^{K}\beta_j\lambda_{irsj}X_{irsjuk}D_i \quad (3)$$

$$+\sum_{i=1}^{P}\sum_{r=1}^{R_i}\phi_{ir}R_{ir} \quad (4)$$

Minimize

$$Z_2 = \sum_{k=1}^{C}\left|\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}}\sum_{j=1}^{M}\sum_{u=1}^{U}\lambda_{irsj}X_{irsjuk}D_i - \frac{1}{C}\sum_{k=1}^{C}\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}}\sum_{j=1}^{M}\sum_{u=1}^{U}\lambda_{irsj}X_{irsjuk}D_i\right| \quad (5)$$

Subject to:

$$\sum_{r=1}^{R_i}R_{ir} = 1 \;\forall i \quad (6)$$

$$\sum_{j=1}^{M}\sum_{u=1}^{U}\sum_{k=1}^{C}X_{irsjuk} = R_{ir} \;\forall i,r,s \quad (7)$$

$$\sum_{u=1}^{U}\sum_{k=1}^{C}X_{irsjuk} \le A\times a_{irsj} \;\forall i,r,s,j \quad (8)$$

$$\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}}X_{irsjuk} \le A\times Z_{juk} \;\forall j,u,k \quad (9)$$

$$A\times\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}}X_{irsjuk} \ge Z_{juk} \;\forall j,u,k \quad (10)$$

$$\sum_{j=1}^{M}\sum_{k=1}^{C}Z_{juk} \le 1 \;\forall u \quad (11)$$

$$\sum_{j=1}^{M}\sum_{u=1}^{U}Z_{juk} \ge L_k \;\forall k \quad (12)$$

$$\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}}\lambda_{irsj}X_{irsjuk}D_i \le T_j \;\forall j,u,k \quad (13)$$

$$X_{irsjuk}, Z_{juk}, R_{ir} \in \{0,1\} \;\forall i,r,s,j,u,k \quad (14)$$

The first objective function is composed of four terms and it minimizes the total cost. Term (1) denotes inter-cell cost. Term (2) denotes computing, maintenance and overhead cost of machines. Term (3) represents the operating costs of assigned machines. Term (4) denotes set up costs of selected routes.

The Second objective balances the workloads assigned to cells. The absolute value in (5) consists of two terms: the first term calculates the workload assigned to each cell and the second term denotes the average workload. Generally, this objective minimizes the difference between the total workload of each cell and the average workload considering all the cells.

Constraint (6) ensures that only one route is selected for producing each part. Constraint (7) ensures that machines must be assigned to all the sequences of a selected route. Constraint (8) guarantees that only when machine j is needed for sequence s of part p along route r, variable X_{irsjuk} can assign it to a location. In any other

$$\sum_{q=1}^{N_g} b_q^1 = 1 \tag{24}$$

$$OBJ_1 =$$

$$\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}-1}\sum_{j=1}^{M}\sum_{j'=1}^{M}\sum_{u=1}^{U}\sum_{\substack{u'=1\\u'\neq u}}^{U}\sum_{k=1}^{C}\sum_{\substack{k'=1\\k'\neq k}}^{C}\gamma_i^{inter} D_i d_{uu} W_{irss+1jj'uu'kk'} \tag{25}$$

$$+\sum_{j=1}^{M}\sum_{u=1}^{U}\sum_{k=1}^{C}\alpha_j Z_{juk} \tag{26}$$

$$+\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}}\sum_{j=1}^{M}\sum_{u=1}^{U}\sum_{k=1}^{K}\beta_j \lambda_{irsj} X_{irsjuk} D_i \tag{27}$$

$$+\sum_{i=1}^{P}\sum_{r=1}^{R_i}\phi_{ir} R_{ir} \tag{28}$$

$$OBJ_2 - d_2^+ + d_2^- = \sum_{q=1}^{N_g} g_q^2 \times b_q^2 \tag{29}$$

$$\sum_{q=1}^{N_g} b_q^2 = 1 \tag{30}$$

$$\sum_{k=1}^{C} \left(\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}}\sum_{j=1}^{M}\sum_{u=1}^{U}\lambda_{irsj} X_{irsjuk} D_i - \frac{1}{C}\sum_{k=1}^{C}\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}}\sum_{j=1}^{M}\sum_{u=1}^{U}\lambda_{irsj} X_{irsjuk} D_i \right) = f_1 - f_2 \tag{31}$$

$$OBJ_2 = f_1 + f_2 \tag{32}$$

$$\sum_{r=1}^{R_i} R_{ir} = 1 \;\; \forall i \tag{33}$$

$$\sum_{j=1}^{M}\sum_{u=1}^{U}\sum_{k=1}^{C} X_{irsjuk} = R_{ir} \;\; \forall i,r,s \tag{34}$$

$$\sum_{u=1}^{U}\sum_{k=1}^{C} X_{irsjuk} \le A \times a_{irsj} \;\; \forall i,r,s,j \tag{35}$$

$$\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}} X_{irsjuk} \le A \times Z_{juk} \;\; \forall j,u,k \tag{36}$$

$$A \times \sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}} X_{irsjuk} \ge Z_{juk} \;\; \forall j,u,k \tag{37}$$

$$\sum_{j=1}^{M}\sum_{k=1}^{C} Z_{juk} \le 1 \;\; \forall u \tag{38}$$

$$\sum_{j=1}^{M}\sum_{u=1}^{U} Z_{juk} \ge L_k \;\; \forall k \tag{39}$$

$$\sum_{i=1}^{P}\sum_{r=1}^{R_i}\sum_{s=1}^{S_{r_i}} \lambda_{irsj} X_{irsjuk} D_i \le T_j \;\; \forall j,u,k \tag{40}$$

$$X_{irsjuk}, Z_{juk}, R_{ir}, b_q^1, b_q^2 \in \{0,1\} \quad \forall i,r,s,j,u,k,q \tag{41}$$

$$d_1^+, d_1^-, d_2^+, d_2^-, f_1, f_2, W_{irss+1jj'uu'kk'} \ge 0 \text{ And } real \quad \forall i,r,s,j,j',u,u',k,k' \tag{42}$$

4. Solving the Mathematical Model

4.1. Exact method

In this part the modified model is solved by LINGO9.0® using branch and bound method. Two randomly generated examples of sizes are generated and are solved by the aforementioned software. The general information of examples is presented in Table 1and the decision variables of example 2 are shown in Table 2and Table 3.

Table 1
Randomly generated examples and exact method results

	Example Sizes				Model Sizes		Lingo 9.0 Results	
	No. of Parts	No. of Machines	No. of Locations	No. of Cells	No. of Variables	No. of Constraints	CPU Time(s)	Achievement Fun.
Example 1	3	5	5	2	6978	25086	18	1266850
Example 2	4	5	7	3	79521	306549	671	970308

shows a general form of a chromosome. First matrix is a $P \times \max_i(R_i)$ matrix which represents the variable R_{ir}. The rows of this matrix show the parts, and the columns show the possible routes; therefore, as an example, if route 3 is selected for part 1, then all of the elements of row 1 is zero except R_{13} which is equal to 1. This matrix configuration satisfies constraint (6).

Second part of the chromosome is a $U \times C$ matrix whose rows refer to locations and the columns refer to cells. This matrix represents the variable Z_{juk}. As an example, if machine 2 is assigned to location 4 and location 4 is grouped in cell 2, the element $Z_{42} = 2$ and the other elements of row 4 are equal to 0. Constraint (11) is satisfied by this matrix and the number of machines for each cell is measured by counting non-zero elements of each column of the matrix. It is necessary to consider constraint (12) while filling second matrix.

Third part of the chromosome is a $P \times \max_i \max_r(S_{r_i})$ matrix in which the rows refer to parts and the columns represent the sequences. The elements of this matrix refer to locations which contain needed machine for that sequence. For example, if element of row 3 and column 2 is equal to 4, it means the second operation of part 3 is performed by the machine assigned to location 4. The collection of all the three matrices represent variable X_{irsjuk}.It is worth noting that the constraints (7), (8), (9), (10) and (13) should be considered while filling the third matrix.

An example for chromosome representations is shown in Fig. 2.

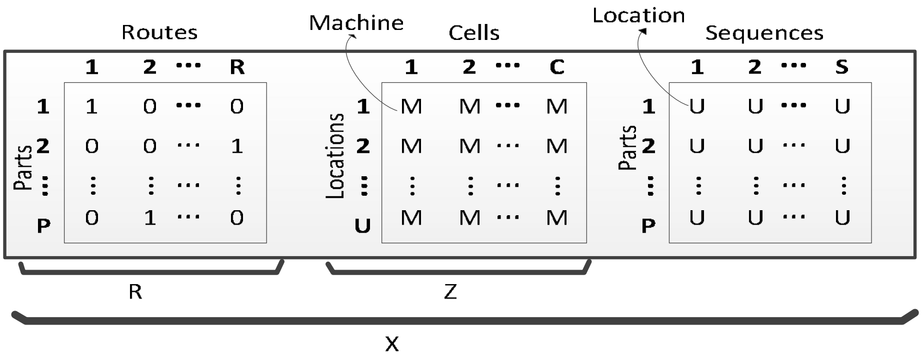

Fig. 1. Chromosome representation

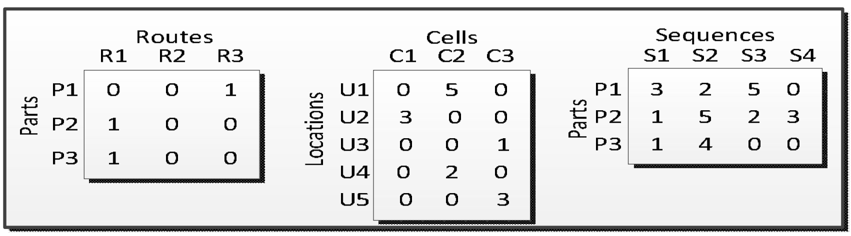

Fig. 2. Example for chromosome representation

Objective function is calculated based on MCGP. Two $1 \times N_g$ matrices are defined in which N_g is the number of aspiration levels used by decision maker. Each of these matrices shows the selected aspiration level for goals. For example if the 4thaspiration level is selected for goal 2, then the element b_{14} is equal to 1 and all other elements are equal to 0 (Fig. 3).Finally, the total deviation is calculated for each chromosome.

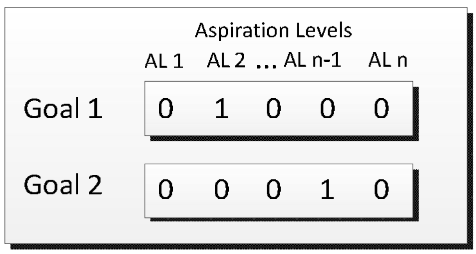

Fig. 3. Example for selecting aspiration levels