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Considering Assembly Operations and Product Structure for Manufacturing Cell Formation

M.B. Aryanezhad, and J. Aliabadi

***Abstract*—**This paper considers the integration of assembly operations and product structure to Cellular Manufacturing System (CMS) design so that to correct the drawbacks of previous researches in the literature. For this purpose, a new mathematical model is developed which dedicates machining and assembly operations to manufacturing cells while the objective function is to minimize the intercellular movements resulting due to both of them. A linearization method is applied to achieve optimum solution through solving aforementioned nonlinear model by common programming language such as Lingo. Then, using different examples and comparing the results, the importance of integrating assembly considerations is demonstrated.

***Keywords*—**Assembly operations and Product structure, Cell Formation, Genetic Algorithm.

I. INTRODUCTION

CELLULAR MANUFACTURING SYSTEM (CMS) is one of the most important applications of Group Technology (GT) for improvement of productivity in batch-type production systems especially while there is high variety product type with relatively low volume for each one and lot sizes are small. In fact, this manufacturing system takes into account the mass production advantage in *flow line* with remaining the existent flexibility in *job shop*.

Regarding to the common definition of CMS (without considering assembly details), production facilities are seprated to several different groups of machines which each group process a part family so that every part type ideally can be produced only in an individual cell. Thus, the objective of CMS design is categorizing parts and machines and deviding production system into several subsystems so that these subsystems be managed so easier than whole system.

So far, many studies have been analyzed the relative performance improvement when converting from job shop to CMS that some of them is as follow: Purcheck [1] applied linear programming techniques to a group technology problem. Albadawi et al. [2] proposed a new mathematical approach for forming manufacturing cells that involves two phases. In the first phase, machine cells are identified by applying factor analysis to the matrix of similarity coefficients. In the second phase, an integer-programming model is used to assign parts to the identified machine cells. Shafer et al. [3] has presented a mathematical programming model to address the issues related to exceptional elements. Wang [4] presented a linear assignment algorithm for machine-cell and part-family formation for the design of cellular manufacturing systems. The present approach begins with the determination of part-family or machine-cell representatives by means of comparing similarity coefficients between parts or machines and finding a set of the least similar parts or machines.

But nonetheless, the number of researches that proceed to the role of the assembly and its performance evaluation, is very negligible. About the same, Johnson [5] has mentioned that prior researches on factors influencing performance improvement through cell conversions has primarily focused on the conversion from a functional to a cellular layout. Therefore, he has used simulation models based on data collected from the plant to estimate the marginal impact each factor change had on the estimated performance improvement resulted by converting assembly lines to assembly cells. Sengupta and Jacobs [6] has compared serial assembly lines with two different cellular systems using simulation models, to highlight guidelines which type of them is more appropriate than the other. In the research by Gravel et al. [7], an interactive tool for designing manufacturing cells for an assembly job-shop is peresented. They have shown that a cellular configuration is not always desirable and discuss the conditions where this is so.

The role of assembly details for designing the manufacturing system is very important. Because, on the one hand, many of products composed from at least two components, need assembly operations (Fig. 1); and on the other hand, the importance of systems which be able to assemble a small batch of customized products quickly, are increasing. In addition, manufacturing systems integrated with assembly operations will obtain a variety of benefits such as reduction of work-in-process inventories between production of parts and assembly of the finished product, increase of output of the manufacturing system, easier production management, and etc. It should be noted when there are assembly operations in a manufacturing environment, implementation of common CMS may not be effective. Consequently, to overcoming the disadvantages associated with that and suggesting guidelines for selection of best system, assembly details should be considered in CMS design.

M.B. Aryanezhad, Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran (e-mail: mirarya@iust.ac.ir).

J. Aliabadi, Department of Industrial Engineering, Iran University of Science and Technology, Postal Code: 16846-13114, Hengam Ave., Narmak, Tehran, Iran (corresponding author Phone: +98 21 77240540; Fax: +98 21 77240540; e-mail: jamal_aliabadi@yahoo.com).

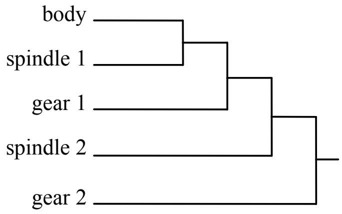

Fig. 1 An example of assembly tree [8]

In some researches, Group Assembly (GA) is defined as a part of GT for designing and managing the assembly systems. Similarly, we can consider Cellular Assembly (CA) as an application of GA and as a part of CMS. Hereof Panchalavarapu and Chankong [9] have presented a new definition for Cell Formation Problem (CFP): "identifying machine cells, part families and a combination of subassemblies so that once the part families are completely processed within a cell, they are also assembled within the cell. The managers of individual cells are now responsible for producing finished subassemblies instead of part families…. The goal of the cellular system design should be to minimize overall material flow resulting in the system due to processing and assembly of parts". For this purpose, they proposed a mathematical model to determine assignment of parts, machines, and subassemblies to manufacturing cells. Their proposed model employs a similarity between part, machine, and subassembly using the part-machine incidence matrix derived from the part routing information, and part-subassembly incidence matrix derived from the product structure. They properly declared that "in a realistic manufacturing environment a group of parts constitute a subassembly and a group of subassemblies constitute a higher level subassembly and so on", but their proposed model has not been included some important parameters such as precedence requirements for assembly, demand for products, and other parameters.

In this paper a nonlinear model is developed for integrating assembly operations and product structure to the cell formation problem (CFP). The proposed model dedicates machining and assembly operations to manufacturing cells so that minimizing the intercellular movements resulting due to both them. For solving aforementioned model, a linearization method is applied and then using different examples, the results are compared to those of not considering the role of assembly.

This paper is organized as follows: Section II proposes a new mathematical model for taking into account assembly operations and product structure to form manufacturing cells. Section III describes the characteristics of proposed model with respect to other research in literature on CMS design. In Section IV, the computational results for different test problems in literature are used to evaluate the proposed model. Finally, Section V concludes the obtained results of this research.

II. MATHEMATICAL MODEL FOR CELL FORMATION

A. *Problem Description*

In modeling the CFP, it is similarly to Panchalavarapu and Chankong [9] assumed that there is only one finished product which its structure and existent parent/child relationships are specified. In addition, creatable items are included two types: individual parts (which contain only the machining consecutive operations and their role is always child) and assembly items (which are composed from a number of components and don't have machining operations).

Production volume of all of the components is identified regarding to structures of final product and its demands, and also a parent item could have any number of its a child type. There is only one process route for each part and also each operation is just processed by one machine and in one cell.

Lower & upper bound for the number of machines within each cell is determined, but the number of cells is not predefined and it is specified after solving the model.

B. *Indices*

p: Index indicating part type with machining operations (p=1,2,…,P).

q: Index for operations of part type p (q=1,2,…,Q_p);

i,j: Indices indicating the assembly items so that i is parent and j is child for each relationship (i,j=1,2,…,I; $j\neq 0$; i=0 that is finished products);

IDE_i: Set of immediate children of parent type i $\{j=p|\ p$ is child of $i\}$

m: Index of machine types (m=1,2,…,M); m_p^q indicates the machine related to q-th operation of part type p;

l: Index of cells (l=1, 2,…, C);

C. *Input Parameters*

v_p: Production volume of part type p

v_i: Production volume of assembly item type i

n_i^p: Number of child items of type p used for producing parent item type i

n_i^j: Number of child items of type j used for producing parent item type i

LB: Minimum number of operations (both machining and assembly) in each cell

UB: Maximum number of operations (both machining and assembly) in each cell

D. *Decision Variables*

$$X_{(m_p^q)l}=\begin{cases}1, & \text{if machine related to } q\text{-th operation of part type } p \text{ is assigned to cell } l\\ 0, & \text{otherwise}\end{cases}$$

$$Z_{il} = \begin{cases} 1, \text{ if item } i \text{ is assembled in cell } l \\ 0, \text{ otherwise} \end{cases}$$

$$C_l = \begin{cases} 1, \text{ if cell } l \text{ is formed} \\ 0, \text{ otherwise} \end{cases}$$

E. Mathematical Model

$$\textbf{Min} \sum_{l=1}^{C} \sum_{p=1}^{P} \sum_{q=1}^{Q_P-1} v_p X_{(m_p^q)l} \left(1 - X_{(m_p^{q+1})l}\right) + \tag{1}$$

$$\sum_{l=1}^{C} \left[\sum_{i=0}^{I} \sum_{j \in IDE_i} n_i^j Z_{il} (1 - Z_{jl}) + \sum_{i=0}^{I} \sum_{p \in IDE_i} n_i^p Z_{il} (1 - X_{(m_p^Q)l}) \right]$$

s.t.

$$\sum_{l=1}^{C} Z_{il} = 1 \qquad \forall i \tag{2}$$

$$\sum_{l=1}^{C} X_{ml} = 1 \qquad \forall m \tag{3}$$

$$2 * C_l \geq Z_{il} + X_{ml} \qquad \forall i, m, l \tag{4}$$

$$LB \cdot C_l \leq \sum_{m=1}^{C} X_{ml} \leq UB \cdot C_l \qquad \forall l \tag{5}$$

$$X_{ml}, Z_{il}, C_l = \{0,1\} \qquad \forall m, i, l \tag{6}$$

Objective function in Eq. (1) contains two terms:

- The first term explains inter-cell movement resulted by the machining operations.
- The second term represents the number of inter-cell movement resulting due to the assembly operations that itself has two parts. First part is for when the child item doesn't have machining operation so it's assembly item type while in second part the child item has machining operations so regarding to assumptions it's not assembly item type. It must be attended that a part type *p* is as the lowest item in BOM, thus for calculating its movements resulted by assembly operation related to corresponding parent item(s), the last operation of above part should be took into account.
- Eqs. (2) & (3) indicate that each assembly operation and machine type respectively is assigned to one cell. Constraint (4) ensures that a cell is formed if assembly or machining operation is assigned to it. Eq. (5) limits the minimum and maximum number of machines in each cell. Finally, Eq. (6) specifies situation of decision variables.

F. Linearization of the Mathematical Model

The objective function in Eq. (1) has nonlinear terms because of multiplying the decision variables into each others. To linearize the model, each nonlinear term must be substituted by a new variable as following:

$$W_{(m_p^q)l} = X_{(m_p^q)l} (1 - X_{(m_p^{q+1})l}) \qquad \forall p, q < Q_p, l \tag{7}$$

$$H_{ijl} = Z_{il} (1 - Z_{jl}) \qquad \forall i, j \in IDE_i, l \tag{8}$$

$$BKW_{ipl} = Z_{il} (1 - X_{(m_p^Q)l}) \qquad \forall i, p \in IDE_i, l \tag{9}$$

Regarding to relation (7), $W_{(m_p^q)l}$ equals 1 when the subsequent operations *q* and *q+1* of part *p* are performed in two distinct cells. Also if the assembly operation of parent and child- which both are assembly items and child doesn't have machining operation- is performed in different cells, H_{ijl} equals 1. For BKW_{ipl} it equals 1 when for a pair of parent and child- which child have machining operation- the assembly item of parent and the last machining operation of child is not performed in the same cell. For each of new variables to equal 1, terms of RHS (Right-Hand-Side) of corresponding change must equal 1. According to above descriptions and change equations, linearization constraints of new variables are as following:

- Constraints of new decision variable $W_{(m_p^q)l}$

$$W_{(m_p^q)l} \geq X_{(m_p^q)l} + (1 - X_{(m_p^{q+1})l}) - 1 \qquad \forall p, q < Q_p, l \tag{10}$$

$$2 W_{(m_p^q)l} \leq X_{(m_p^q)l} + (1 - X_{(m_p^{q+1})l}) \qquad \forall p, q < Q_p, l \tag{11}$$

- Constraints of new decision variable $W_{(m_p^q)l}$

$$H_{ijl} \geq Z_{il} + (1 - Z_{jl}) - 1 \qquad \forall i, j \in IDE_i, l \tag{12}$$

$$2 H_{ijl} \leq Z_{il} + (1 - Z_{jl}) \qquad \forall i, j \in IDE_i, l \tag{13}$$

- Constraints of new decision variable $W_{(m_p^q)l}$

$$BKW_{ipl} \geq Z_{il} + (1 - X_{(m_p^Q)l}) - 1 \qquad \forall i, p \in IDE_i, l \tag{14}$$

$$2 BKW_{ipl} \leq Z_{il} + (1 - X_{(m_p^Q)l}) \qquad \forall i, p \in IDE_i, l \tag{15}$$

It should be noticed that regarding to the positive coefficients of new variables in objective function and also because of its type which is minimization; these variables obviously would adopt 0. Thus, if at least one of the corresponding initial variables is became 0, the related new variable obtains certainly zero and therefore the second type of above constraints (i.e. Eqs. (11), (13) and (15)) are not needed. Consequently, the following linear model is gained which is solved by Lingo programming language.

$$\textbf{Min} \sum_{l=1}^{C} \left[\sum_{p=1}^{P} \sum_{q=1}^{Q_P-1} v_p W_{(m_p^q)l} + \sum_{i=0}^{I} \sum_{j \in IDE_i} n_i^j H_{ijl} + \sum_{i=0}^{I} \sum_{p \in IDE_i} n_i^p BKW_{ipl} \right] \tag{16}$$

s.t.

Eqs. (2) – (5), (10), (12), (14)

$$\begin{aligned} & X_{ml}, W_{(m_p^q)l} = \{0,1\} && \forall m, p, q < Q_p, l \\ & Z_{il}, H_{ijl}, = \{0,1\} && \forall i, j \in IDE_i, l \\ & BKW_{ipl} = \{0,1\} && \forall i, p \in IDE_i, l \end{aligned} \tag{17}$$

III. PROPERTIES OF PROPOSED MODEL

By review of researches in the literature on CMS design, it is almost clear that assembly details and product structure is not regarded except for one paper by Panchalavarapu and Chankong [9] in which the role of assembly operations in modeling for CFP is incompletely considered. Their proposed model applies an approach for integration of assembly aspects into the manufacturing cell based on the exceptional elements (EE) resulting due to processing and assembly operations which has several defects. Hence the proposed model in this paper has been tried to eliminate its drawbacks as following:

- ***Calculating the EEs resulting due to assembly operations more properly***

The number of EEs resulting due to assembly operation through the part-subassembly incidence matrix (which is used in [9]) may not be accurate. Because, it always calculates the intercellular movements for parts on the lowest level of a parent item's children whereas its immediate children must be considered. In the proposed model of this paper, this defect is solved.

- ***Considering more accurate criterion for reduction of dependencies between cells***

It must be noticed that the best criterion for considering interdependent (or dependent reduction) between cells is to minimizing intercellular movements which may be different from (further or minor than) the number of EEs. In modeling the CFP in this research, this subject is considered.

- ***Not considering the assignment of part families as a part of CFP***

In prevalent definition of CFP, a stage as grouping parts into some families has been mentioned that doesn't need to be considered. More over the part family number for each part should not be as a decision variable. Hence, in contrast to [9], proposed model assigns the cell number to each operation instead of to parts.

IV. COMPUTATIONAL RESULTS AND COMPARISON

To evaluate the proposed model, eight different test problems from the literature are considered as shown in Table I.

TABLE I
INFORMATION RELATED TO EXAMPLES

Problem #	**Ref.**					
		Number of non-assembly Items	**Number of assembly items**	**Number of Operations**	**Number of Machines**	**Number of Cells**
1	**McCormick et al. [10]**	4	-	8	4	2
2	**Xiaodan et al. [11]**	5	-	11	5	2
3	**Heragu [12]**	6	-	15	7	2
4	**Irani [13]**	6	-	14	10	3
5	**Panchalavarapu and Chankong [9]**	7	7	15	8	2
6	**Singh et al [14]**	8	-	23	6	2
7	**Chan & Milner [15]**	10	-	46	15	3
8	**McAuly [16]**	10	-	39	12	3

Since assembly operations and product structure have not been considered in the literature as proposed models, the required data related are not available. Therefore, these input data are randomly generated.

All the test problems have been solved by Lingo 8.0 on Pentium IV 2 GHz machine both with and without considering assembly operations and product structure. Table 2 summarizes the results of solutions and a comparison between the intercellular movements in two situations.

TABLE II
COMPARISON OF COMPUTATIONAL RESULTS OF INTERCELLULAR MOVEMENTS IN TWO SITUATIONS

Problem #	**without integrating assembly details**		**with assembly consideration**	
	due to processing	**due to assembly**	**due to processing**	**due to assembly**
1	0	7	0	7
2	51	8	51	4
3	165	15	165	7
4	325	12	325	9
5	0	8	2	4
6	2226	20	2226	20
7	520	32	520	29
8	3724	22	3724	22

As evidenced in above table, the number of intercellular movements resulting due to the processing is identical for both situations. It is because of considering the demand of final product and accordingly the production volume of its components which are bigger than the counts of each given child in child/parent relationships. But in all the test problems, the number of intercellular movements resulting in situation with assembly consideration is equal or less than the other situation. Fig. 2 shows this matter clearly:

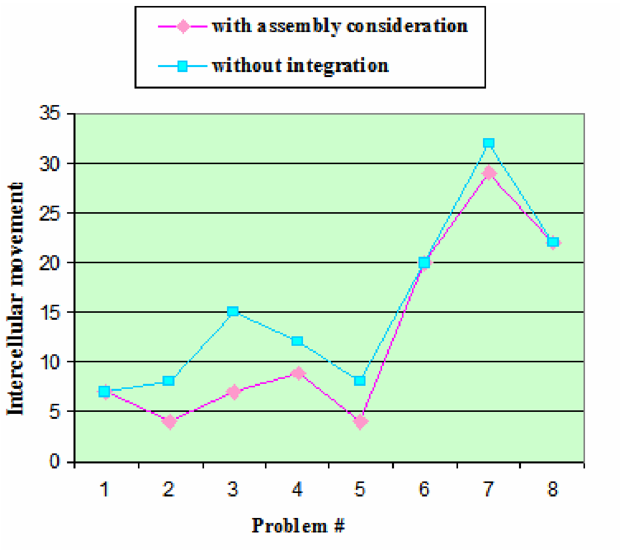

Fig. 2 Comparative graph for intercellular movements resulting due to the assembly operations in two situations

V. CONCLUSION

There are many researches in literature on CMS design, nonetheless the assembly details and product structure are not considered properly. In this paper, a new mathematical model is developed to integrating the assembly considerations in modeling CFP. The objective function of proposed model is to minimize the intercellular movements resulting due to the both processing and assembly operations. Model is such a way that all precedence requirements and prerequisite relations according to product structure are considered. The linearization method has been applied for solving model by Lingo programming language, but developing a meta-heuristic algorithm can be interesting for future research to solve large-size problems. In addition, there are other valuable issues for future investigations such as considering the time and cost of operations, flexibility through the alternative plans for production, and so on.

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