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Heuristic for Enabling Lean Characteristics in Cellular Manufacturing using Reconfigurable Machines

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***Abstract* – Due to the rigidness of cellular manufacturing system (CMS), it lacks adaptability which is the ability to respond to changing products, product mix and production capacity, hence loosing competency in dynamic manufacturing environment. Reconfigurable machine tools (RMTs) are the great means to propel flexibility in CMS to enable a high degree of system responsiveness to frequent changes in cost effective way. In this paper, RMTs are used to exert lean characteristics in CMS by inheriting the desirable properties of RMTs. A heuristic is developed for embedding lean characteristics into machine cell design. The emphasis of this research is the formation of machine cells driven by specific product mix. An application example is included to illustrate the cellular model.**
***Key words* – Cellular manufacturing, Takt, Reconfigurable machine tools, Cell design**

I.INTRODUCTION

Machine cells have been one of the most competitive strategies to improve productivity on production floor. The adoption of machine cell in manufacturing, termed as cellular manufacturing (CM), is regarded as transition from mass production to batch production. A machine cell is an arrangement of machines to process a sequence of operations for a specific kind of jobs. It exploits the similarities in operations and machine requirements of different jobs to rationalize the process variation, thus to reduce set up times and lead times. The benefits of CMS implementation reflects through improvement of production efficiency, reduced setup times, lower cycle times, reduced work-in-process inventory level, lower material-handling times, lower product defect rates, lower machine idle times, simplified material flow, smaller space requirements, lower costs, etc. [1].

The concept of cellular manufacturing has been widely exercised by various industries and the potential of CM is continually being explored. In the recent developments, the utility of machine cells have been investigated to improve productivity in different manufacturing environments. Early surveys demonstrate that the cellular layout had been found most promising strategy in manufacturing industries but with pragmatic changes in manufacturing environment, the applicability of machine cell has become a subject of discrepancy among researchers due to inadequate flexibility of CM [2].

There are a number of methodologies developed for cell formation taking upon different perspectives and various production parameters taken into account. The effort is made to incorporate a certain degree of flexibility into cellular manufacturing to cope up with frequent and unpredictable changes in manufacturing. However, these criterion replicate the day-to-day challenges in the manufacturing scenario, they follow a structured approach e.g. physical location, capacity, operational functionality etc. These constraints lead to the rigidness of machine cells and often place a high impact on productivity of cellular manufacturing. To sustain competitiveness under dynamic and unpredictable environment, Saad [3] introduced the concept of reconfigurability into CM to eradicate cell deficiency such as load imbalance among cells and poor cell utilization. Reconfigurability allows a manufacturing system to adjust its components or subsystems to react rapidly and cost effectively according to market needs.

This paper presents a suitable manufacturing environment for CM implementation and various key lean characteristics such as continuous flow, synchronization, takt/rythm, just-in-time is achieved using RMTs.

II. LITERATURE REVIEW

The concept of reconfigurable manufacturing system (RMS) was evolved by Koren et.al. [4] to cope up with unpredictable market changes on three folds; capacity, functionality and cost. The reconfigurability in a system can be routed through customization, convertibility, scalability, modularity, integrability, and diagnosability [5]. A reconfigurable machine is the essential element of RMS, encompasses a modular configuration with an adjustable structure that allows the adjustments of its own resources to enable required reconfiguration characteristics. The reconfigurable machine is equipped with basic module and a library of auxiliary modules. The basic modules are structural in nature, such as base, columns, slide ways, and tables, and auxiliary modules are kinematical or motion-giving, such as spindles, tool changers, etc. The auxiliary modules are custom designed to provide different levels of reconfigurability. RMTs are tailored to perform specific sets of operations in a given range of cycle times [6]. The capacity and functionality of such machines are not fixed but can be changed in response to market demand. The application of RMTs for a part family has been extensively justified by Koren et. al. [4]. In recent developments, various researchers have presented different topologies for cell design incorporating different reconfiguration characteristics.

Pattanaik et. al. [7] proposed a cell formation methodology using reconfigurable machines with the capability of performing multiple operations. The methodologies followed a clustering approach in which the similarities among operations were investigated first based on production flow information followed by machine cells are identified using machine–operation compatibility measure and operation diversity measure for a group of machines. In another work, a synergic integration of CMS and RMS was presented by Xing et. al. [8] in which the processing capabilities of RMTs are used to counter bottleneck machines in cellular manufacturing. An application of RMS with each machine configuration capable of performing one or more operations with different processing times was demonstrated by Ossama et. al. [9] for multi-period machine cell formation. Eguia et. al. [10] included production capacity and functionality characteristics of RM while developing a reconfigurable model of cellular manufacturing system. The model was developed using reconfigurable machines of infinite capacities and auxiliary modules capable of performing multiple tasks taking reconfiguration costs into account. The methodology followed hierarchical approach where part families were determined first followed by the RMT assignment.

In the present work, RMTs capable of altering only their capacities are considered in order to compensate any fluctuations in demand. Multiple machines are allowed in different cells to reduce the material flow complexity and control. Thus, a machine cell can work independently and can be treated as a single workstation.

III. APPLICATION ILLUSTRATION

It is a very general practice that a company often offers products with variety with a little variance such as automobile, electronic components etc. The present study is based on the same theme where multiple products are manufactured and these products are assemblies of various components that are assembled in the similar manner. The design and manufacturing requirements of the components are almost similar. As depicted in Figure 1, a company produces four products P_1, P_2, P_3 and P_4 using the same assembly line. The components of these products can be grouped into appropriate part families termed as component families in the present work and consequently produced in machine cells. These cells shall connect the assembly line at the appropriate station or location to feed the required components for the product being assembled.

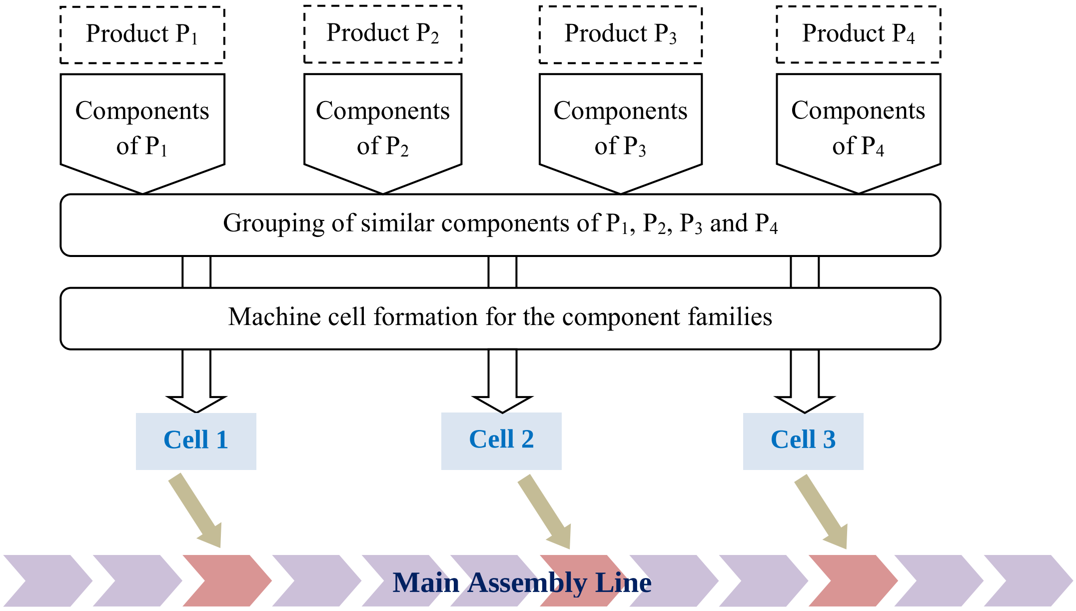

Fig. 1 Linking of Machine Cells to Lean Assembly Line

IV. THE HEURISTIC

From the available literature, it is found that the formation of reconfigurable machine cell (RMC) has got less attention from the researchers. Although few good works are published but the procedures are computationally complex. Sharing of resources and flexible boundaries of machine cells often lead to complicated material flow patterns and complex production control strategies. Hence, a simple heuristic is proposed here for the formation of independent machine cells. The ideal batch size is one as applied in lean philosophy. The following assumptions are considered before developing the heuristic:

a. Each component has a fixed process routing.
b. Each RMT has its own basic and auxiliary modules.
c. The RMTs are selected based on their best suitability for one specific operation.
d. The capacities of the RMTs are known and perform within a specific range of cycle times.
e. The machining time includes the setup time, however the reconfiguration time is considered separately.
f. The machine reconfiguration is not necessary for the same component type but may be necessary for each new component type.
g. Reconfiguration time includes module change times.
h. Multiple identical machines can be located in different cells to eliminate inter cellular movement where as intracellular movement are not considered.

Let,

i	Product index, $i = 1, 2, 3, ..., I$
j	Component index, $j = 1, 2, 3, ..., J$
m	Machine index, $m = 1, 2, 3, ..., M$
c	Cell index, $c = 1, 2, 3, ..., C$
P_i	Product type i
V_i	Demand of product type i
C_{ij}	Component j of product type i
T_{ijm}	Machining time for component j of product type i on machine m
RT_m	Reconfiguration time for machine type m
RC_i	Reconfiguration time for product type i
CC_i	Cycle time for product i
F_{ij}^c	Processing time for component j of product i in cell c

The similarity between the components is calculated taking into account the number of operations. Similarity coefficient between two components a and b is given by [11],

$$SC_{ab} = \frac{\sum_{m=1}^{M} \alpha_{ma}\ \alpha_{mb}}{\sum_{m=1}^{M} \alpha_{ma}} \qquad \text{... (1)}$$

For, $a \neq b$ and $\alpha_{ma} = 1$ if component a is processed by machine m, otherwise 0. '0' similarity coefficient implies components are purely dissimilar and they do not have a single common machining operation while '1' indicates components have all the operations common.

The processing time for component j of product i in cell c is calculated using the following relationship:

$$F_{ij}^c = \sum_{j=1}^{J}\sum_{m=1}^{M} X_{ijc}\ Y_{ijm}\ T_{ijm} \qquad \text{... (2)}$$

Where, $X_{ijc} =$ 1 if component j of product i is assigned to cell c
0 otherwise

$Y_{ijm} =$ 1 if component j of product i needs to be processed on machine m
0 otherwise

The reconfiguration time for a product type is determined by,

$$RC_i = \max\ \langle Y_{ijm}\ RT_m \rangle \qquad \text{... (3)}$$

$\forall\ j \in [1, J]$ and $\forall\ m \in [1, M]$

Total production time is calculated by,

$$T = \sum_{i=1}^{I}\left((V_i * CC_i) + RC_i\right) \qquad \text{... (4)}$$

The heuristic follows hierarchical clustering approach where component families are formed first followed by machines cells. The heuristic starts with the input of bill of material and part-operation matrix for components for all the products type. It provides a back track solution where the production capacities of RMTS are adjusted to fulfil the known demand in the given time period. In order to attain lean characteristics, all the cells are synchronized with the assembly line and are made able to produce components as per demand of the main assembly line for a product type. The machine cells will perform in a rhythm with assembly flow and follow the takt of the assembly line. The steps of the proposed heuristic are as follows:

Step 1: Calculate the similarity coefficient between components using equation (1) and prepare a similarity matrix.

Step 2: Assign a threshold value of similarity coefficient to investigate the possible components families.

Step 3: Select RMTs best to the operations required for the component families and assign them to corresponding cells. Form independent machine cells by allocating multiple machines where a machine is required in two or more than two cells.

Step 4: Balance the work load among the cells for each product type considering a moderate capacity of RMTs. The cell work load is determined by equation (2). The balanced cell gives the ideal cycle time for a product (CC_i).

Step 5: Calculate the total production time required for a product mix. If (total available time ≈ total production time), then go to step 10.

Step 6: Determine the reconfiguration time to adjust the cycle time of a product type using equation (3).

Step 7: Select a product with the least reconfiguration time. Adjust the machines required for that product to obtain a new ideal cycle time for the product (CC'_i).

Step 8: Calculate the total production time with new cycle time using equation (4).

Step 9: Repeat step 7 and 8 until (total available time ≈ total production time).

Step 10: Stop.

For the present scenario, a higher threshold value of similarity coefficient will include components with higher degree of similarities and less number of families will be formed but yield higher cell utilization. A lower threshold value will lead to poor cell performance. Hence, an optimal threshold value must be selected.

In this heuristic, the cycle times of products are adjusted according to the change in product mix. Cells are synchronized with the production line and made to produce as per the required demand. In this way, the various key characteristics of a lean production system can be achieved such as continuous flow, synchronization, takt, etc.

V. CONCLUSION

The following conclusions can be drawn from this research work:

1. The rigidness of CMS can be overcome by using RMTs while designing machine cells. The adjustable structure and modular configuration of RMs provide the highest degree of flexibility in CMS to respond rapidly to changing circumstances in cost effective way.
2. The machine cells can be reconfigured by different ways according to the nature of problem.
3. The proposed heuristic can be conveniently applied for implementing a cellular layout where the products are with similar features.
4. Cellular manufacturing has been already regarded as a tool for lean manufacturing, but lean attributes such as takt are yet to be incorporated in cell design.

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