

Dynamic Cellular Manufacturing under Multiperiod Planning Horizons

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ABSTRACT: In this paper cellular manufacturing is discussed under conditions of changing product demand. Traditional cell formation procedures ignore any changes in demand over time from product redesign and other factors. However given that in today's business environment, product life cycles are short, a framework is proposed that creates a multi-period cellular layout plan including cell redesign where appropriate. The framework is illustrated using a two stage procedure based on the generalized machine assignment problem and dynamic programming. This framework is conceptually compared to virtual cell manufacturing, which is useful when there is uncertainty in demand rather than anticipated changes in demand. Thus this paper should be useful to both researchers and Practitioners who deal with demand changes in cellular manufacturing.

KEYWORDS: Cellular Manufacturing, flexibility, facility layout, dynamic cells, virtual cells

I. INTRODUCTION

In order to be successful in today's competitive manufacturing environment managers have had to look at new approaches to facilities planning. It is estimated that over \$250 billion is spent in the United States alone on facilities planning and re-planning (Tompkins et al., 2003, p10). Thus effective layout planning can yield considerable benefits. One such approach or philosophy is called Group Technology (GT). GT is based on the principle of grouping similar parts into families. This paper focuses on cellular manufacturing (CM), an important aspect of GT. CM concentrates on the formation of groups of machines (cells) that process one or more part-families. Various approaches have been suggested for forming manufacturing cells. However, most of these methods assume that The demand stays constant over long periods of time. But in today's market based and dynamic environment, such demands can change quickly. Rosenblatt (1986) discusses dynamic layout. Good discussions of GT can be found in Burbidge (1963), Suresh and Meredith (1985) and Selim et al.(1998). Techniques range from the simple to the Sophisticated and flexible. The simple techniques usually manipulate part-machine matrices. The sophisticated ones can handle many constraints in forming cells such as maximum cell size, different demands for different products, number of cells and set-up costs.

II. PREVIOUS WORK

Manufacturing cells are created by grouping the parts that are produced into families. This is based on the operations required by the parts. These cells which consist of common machines are then physically grouped together and dedicated to producing these part-families. Cells combine the advantages of flow shops and process layouts such as reduced cycle times compared to jobs shops and increased flexibility and greater job satisfaction as compared to flow shops. There are some disadvantages however. Machines utilization may be lower due to dedication. Also much training is required in order to operate cells effectively. Most cell formation procedures described in Selim et al. Assume that once the cell is formed, the machines will not be moved for a long time. However in many instances, product

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization

Volume 4, Special Issue 3, March 2015

First National Conference on Emerging Trends in Automotive Technology (ETAT-2015)

Organized by

SAE INDIA Velammal Collegiate Club, Velammal Engineering College, Chennai, India on 20th March 2015

demand may change quickly, rendering the current cell obsolete. Thus, depending on the demand, the cellular configurations would have to change over time. We call this problem the dynamic cellular manufacturing problem. Vakharia and Kaku (1993) incorporate long term demand changes into their 0-1 mathematical programming cell design method by reallocating parts to families to regain the benefits of cellular manufacturing.

Similarly new parts are allocated to existing cells. So cells were not rearranged in their multi-period design. Harlahakis et al. (1994) also consider product demand changes during a Multi-period planning horizon. Their design is based on robustness, i.e., designing a cellular configuration that would be effective over the ranges of expected demand over multiple periods. Thus once the cells are designed they are expected to remain unchanged during the multi-period horizon. Similarly Seifoddini (1990) has incorporated probabilistic demand in designing static cells. Askin et al. (1997) have proposed a four stage algorithm that designs cells to handle variation in the product mix. Initially a mathematical programming based method is used to assign operations to machine types. Subsequent phases allocate part-operations to specific machines, identify manufacturing cells and improve the design.

Experiments were also conducted to evaluate the effect of factors such as utilization and maximum cell sizes on the effectiveness of the algorithm. Again, cells once designed are expected to remain unchanged during the planning horizon. We suggest an alternate framework. We propose changing the cellular configuration periodically when the cost-benefit analysis favours such a move. In this way, the cellular layout will be better suited to the demand in each period and thus be more effective and agile during the planning horizon. In addition we propose examining multiple layouts when considering cell redesign in order to incorporate different qualitative and quantitative considerations. Such an analysis can also highlight the need for easily movable machines to ensure that cellular manufacturing is effective throughout the planning horizon.

III. VIRTUAL MANUFACTURING CELLS

Many researchers have suggested the use of Virtual Manufacturing Cell Systems (VCMS) when product demand is uncertain or unpredictable. In a virtual cell, machines are dedicated to a product or a product family as in a regular cell, but the machines are not physically relocated close to each other. McLean et al. (1982) were one of the first to propose such an approach. In a VCMS machines in a functionally organized facility would be temporarily dedicated to a part family. When a job is to be done it is routed to those machines dedicated to the part family. Thus as in physical cells, dominant flow patterns arise. Machines in the virtual cell are set up for that product family. If the demand pattern changes, the machines in any virtual cell can be reassigned to another part family. Since no machines have to be moved, there is really no rearrangement cost.

This is an important advantage since using physical cells in the face of uncertain demand might result in cells having to be rearranged frequently on an ad hoc basis. If the machines are not mobile, this could result in high costs (if the cells are reconfigured) or high inefficiency (if the cells are not reconfigured). Thus, according to Kannan and Ghosh (1996) virtual cells are „flexible routing mechanisms“. Virtual cells combine the advantages of both process layouts and cellular manufacturing. For example, one major disadvantage of

traditional cellular manufacturing is that once cells are formed, the machines in a cell may not be available for parts not dedicated to that cell. Thus the machine utilization may suffer when compared to functional layouts, where machines can be assigned to any part at any time. VCMS avoid this drawback as the machine allocations are only temporary and can be reallocated easily (Prince and Kay, 2003). In addition in a VCMS, a family could have access to multiple machines of the same type. Subsequently if the need arises, some of these multiple machines can be reassigned to a part that needs it in order to ensure equitable sharing of machines (Kannan and Ghosh). One aspect where VCMS would not have an advantage over physical cells is in the amount of travel since in a virtual cell, the layout remains functional and the part may have to travel large distances within the virtual cell. In comparing VCMS to traditional CM, SubashBabu et al. (2000) categorize

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization

Volume 4, Special Issue 3, March 2015

First National Conference on Emerging Trends in Automotive Technology (ETAT-2015)

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CM benefits into three types: (1) human related factor benefits from empowerment in smaller cells, (2) improved flow and control in cells due to having to deal with smaller number of parts and machines, and (3) improved operational efficiency due to similarities, in terms of reduced setup, smaller batch sizes, increased quality, productivity, and agility. They suggest that VCMS may not offer benefits in the first category, while providing considerable advantages in the second and third categories. Benjaafar et al. (2002) suggest that a distributed layout might help in virtual manufacturing. In a distributed layout, machines of the same type are not grouped together as in a process layout but they are distributed through out the facility individually or in clusters. Thus when creating a virtual cell, the required machines from clusters that are located close to each other can be selected.

While still not a physical cell, the distance traveled by the part in its routing can be reduced by using distributed layouts as compared with pure process layouts. Drolet et al. (1989) and Drolet and Moodie (1990) discuss algorithms and scheduling in VCMS, while Drolet et al. (1996) discusses VCMS within the context of the evolution of CM. Recently Ratchev (2001) describes an iterative and concurrent method for designing virtual manufacturing cells through four steps. The first step involves identifying component requirements and generating processing alternatives. Then the boundaries of the virtual cell capabilities are defined, following which the machine tools are selected. The final step is system evaluation. Kannan and Ghosh compare VCMS to CM and process layouts by using simulation. The simulated facility consisted of forty parts and thirty machines. The CM layout consisted of five cells, while the process layout consisted of eight departments. Five different configuration rules for VCMS were considered. These included rules such as; for a machine, giving allocation priority to a family with low average slack per job, or to a family with the fewest remaining machines needed to complete a cell. Inter-family setup times were higher than intra-family setups as is common in practice. The demand pattern had variability (uncertainty) through part mix changes.

Primary performance measures included mean flow time, mean tardiness and the mean and standard deviation of the work in process (WIP). The results showed that the VCMS outperformed both the process layout and CM over a wide range of conditions. When there was less demand uncertainty, the cellular advantages of

VCMS were utilized, while when demand uncertainty was high, the VCMS' ability to quickly reconfigure the cells were utilized. The simulation showed that VCMS allowed jobs to spend less time in queues and setup as compared to process layouts due to dedicated routings and shared family setup. While the VCMS expectedly outperformed cellular manufacturing when setup time was low and demand uncertainty was high (conditions under which CM is not very desirable), the VCMS also outperformed CM when setup time was high and demand uncertainty was low (conditions under which CM has shown to be useful). This was due to the fact that the VCMS had the ability to exploit production similarities while not giving up any flexibility. It was also shown that some of the VCM rules performed poorer than the others. Kannan (1997) further investigates the effect of family configuration on VCMS performance. Prince and Kay (2003) discuss the use of virtual groups (VG) to enhance agility and leanness in production. Both VCMS and VG uses the concept that machines in a cell need not be physically located close to one another.

However, while VCMS focuses on managing the process, VG focuses on the management of products. Group managers would be assigned a team of operators and all the machines required to make complete products or major subassemblies. Thus these groups are likely to be longer lasting than in VCMS. This would make it easier to implement lean and agile concepts in the different stages of production. In a VCMS different machines in a group could be managed by different groups, thus not utilizing the advantage of teams. Thus VGs are an attempt to improve upon some of the disadvantage of VCMS. While VCMS have advantages over CM, it can result in not being able to use the human related factors as stated by SubashBabu et al.

Human factor advantages are difficult to evaluate through computer simulations such as in Kannan and Ghosh, thus sometimes tending to be overlooked. Important human factors aspects of CM include team building, learning, and problem solving. These would be difficult to do without physically grouping cells together. For example, one company in the maintenance, repair and overhaul (MRO) industry that one of the authors is familiar with uses CM. Outside each cell is posted a board where performance indicators such as lead times, WIP, and bottleneck measures are posted. Thus any deterioration in performance can quickly be identified and corrective measures taken. In a VCMS or

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VG where machines are not grouped together, such posting would be difficult. In addition, in a VCMS, just as in a process layout, it is not clear who would be responsible for improvement, since employees work on individual machines and are not responsible for the entire routing. In CM, the team managing the cell would be responsible for the performance.

HP (Hewlett-Packard, 1984) is another example of a company that uses CM for facilitating problem solving. Cell team members regularly spend time brainstorming and solving problems within the cell to improve productivity and quality. This would be more difficult in a virtual cell since team members may be working in different areas of the facility and may not work in proximity to each other. In addition as mentioned before, VCMS and VG may not improve travel times compared to a process layout since the machines in a cell may be located far away from each other. Thus it is important as far as possible to maintain a physical grouping of machines. Dynamic cellular manufacturing is a concept which allows for the physical grouping of cells while allowing cell rearrangement periodically in appropriate situations.

IV. DYNAMIC MANUFACTURING CELLS MODEL

Dynamic manufacturing cells are useful when there are anticipated changes in product demand due to new products. Demand may be said to be dynamic in this situation. For example, one of the authors is familiar with a company that manufactures pressure vessels under contract (including fuel tanks for military aircraft) for a variety of clients. Since these are made under contract the company can forecast the future flow of material quite accurately depending on when they will be starting to work on a particular contracted job. Under such a situation it is advantageous to consider grouping cells physically together and then rearranging them if the material flows changes under a new contract. This will allow them to take complete advantage of CM as well as retain the flexibility through reconfiguring cells on a planned basis.

An example of a four period dynamic cellular manufacturing problem is shown in Figure 1. Let X be the optimal cellular configuration of the layout in period 1. In period 2, if the product demand changes as explained previously, the optimal cellular configuration may also change. Let this be represented by Y in period 2. Similarly, due to further demand changes in period 3, the optimal cellular configuration changes to Z. In period 4, the last period of the planning horizon, Y may again be the optimal configuration. If there was no cost in changing from one optimal cellular configuration to another then the best course of action would be to use the optimal configuration every period. This would result in the most effective cellular system within the multi-period horizon. But rearranging cells has associated costs such as moving machines, lost production time, and relearning.

Thus the decision to rearrange should be taken only after a cost benefit analysis. Further, using a wrong cellular configuration in a period could result in excess shifting costs in subsequent periods. Thus there are two types

of conflicting costs and the objective determining a dynamic or multi-period cellular configuration plan is to minimize the sum of these over the planning horizon. Due to rearrangement costs, it is possible that a sub-optimal cellular configuration is the best one to use in a period as using this sub-optimal cellular configuration might result in lower shifting and lower overall costs. For example, cellular configuration X may be optimal in period 2, but we use configuration Y because it lowers the overall multi-period cost. Since sub-optimal cellular configurations can be used in each period, we have to include every possible cellular configuration in order to ensure overall optimality.

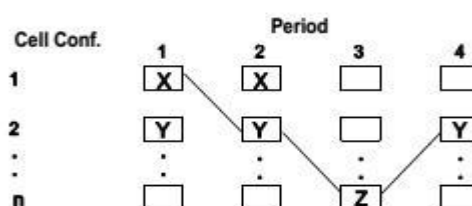


Figure 1: The Dynamic Cellular Manufacturing Model

International Journal of Innovative Research in Science, Engineering and Technology

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Volume 4, Special Issue 3, March 2015

First National Conference on Emerging Trends in Automotive Technology (ETAT-2015)

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Thus, when creating manufacturing cells it is important to take into account not only the interactions between machines but also the changes in product demand. Otherwise our cells will become outdated quickly resulting in excess costs.

V.THE PROPOSED TWO STAGE PROCEDURE

Stage 1 - Solving the static (single period) phase

Let
L_i
A_{ij}
F_{ij}
C*_{ij}

This phase involves solving the machine assignment problem. As mentioned in the previous section, in order to obtain an optimum solution for the problem, all the possible cellular configurations in each period would have to be evaluated. This would correspond to the n configurations shown in Figure 1. However for most practical sized problems, this would be computationally prohibitive as shown in Table 1 for a seven machine problem assuming that a cell has to contain at least two machines

Cell Configuration	Number of Machines Per Cell			Combinations Possible	Number of Combinations
	Cell 1	Cell 2	Cell 3		
1	2	5		7C2X5C5	21
2	2	3	2	7C2X5C3X2C2	210
3	3	4		7C3X4C4	35
				TOTAL	266

Table 1: Possible configurations for a seven-machine problem.

There would be n = 266 different cellular configuration possibilities in each period. For a five period problem there would be 266⁵ or 1.33x 10¹² possibilities in the dynamic (multi-period) phase. This is a huge number

given the small number of machines. Thus most practical sized problems will have to be solved heuristically by including a sample of the cellular configurations possible in each period. The static phase of the framework involves identifying the appropriate cellular configurations from each period that will be included in the dynamic phase of the problem. Since this phase is independent of the second phase, any appropriate method can be used. Thus the proposed procedure is very flexible. The simplest method to generate static cellular configurations would be to do it randomly. In this method, given different cell sizes, the machines would be assigned randomly to each cell. This would give some of the possible cellular configurations.

However, research by Rosenblatt showed that this was not effective. When only s configurations, where s < n, can be included due to computation time restrictions, a good alternative according to Rosenblatt is include the best s cellular configurations instead of generating the s configurations randomly. Alternately if finding the best s combinations is also time prohibitive, s good cellular configurations could be used. If a method with high computation time is used, only a few configurations will be generated. Similarly, if the cellular configurations are created manually using qualitative considerations, only a few configurations may be created. If the algorithm used is quick then many configurations can be generated. A combination of manual and algorithmic solutions can also be used.

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Stage 2 - Solving the Dynamic Phase

From Figure 1, it can be seen that the dynamic cellular manufacturing problem lends itself quite well to dynamic programming (DP). The objective of dynamic cellular manufacturing is to arrive at the best multi-period plan. In order to do this we have to determine the best cellular configuration (state) in each period (stage). The total cost of the plan will minimize the sum of the shifting and material handling costs within the plan horizon. The procedure used is a DP algorithm based on Rosenblatt

Cellular configuration I Rearrangement (sum of shifting costs) cost when changing from cellular configuration L_i to cellular configuration L_j . This cost is independent of the period in which it occurs.

Material handling cost for cellular configuration L_i in period t . This is obtained from the Stage 1 solution. Minimum total costs (material handling and shifting) for all periods up to t where L_i is used in period t .

The combination of cellular configurations with the minimum total cost is chosen based on the following recursive relationship:

$$C^*_{jt} = \text{Min}_i \{ C^*_{it}(t-1) + A_{ij} \} + F_{jt} \quad (1)$$

The DP is solved using backward recursion. Each period in the planning horizon forms a stage and each cellular configuration from Stage 1 forms a state. The two stage algorithm is applied in the illustration in the next section.

VI. CONCLUSION

This paper presented a flexible framework for modeling cellular manufacturing when product demand changes during the planning horizon. This framework can incorporate various types of problem specific situations including qualitative considerations. It is conceptually compared to VCMS which is appropriate under uncertain demands. It is also important to note that using a multi-period planning horizon can shed some light on aspects of cellular manufacturing that may not be available by examining cellular manufacturing based on a one period horizon. The example used in this paper shows that as cell rearrangement costs increase, jobs shops may be preferred to cellular manufacturing. In addition, the example also shows that if one can reduce cell rearrangement costs, then cellular manufacturing will be more rewarding for the organization. Thus it illustrates that in order to make cellular manufacturing viable in a changing demand environment, reduction of layout rearrangement costs as seen in JIT organizations may be important.

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