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A review on methodology for designing flexible cellular manufacturing systems, machine procurement, production planning and dynamic system Re-configuration.

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Abstract

Cell formation in cellular manufacturing deals with the identification of machines that can be grouped to create manufacturing cells and the identification of part families to be processed within each cell. Dynamic and random variations in part demands can negatively impact cell performance by creating unstable machine utilizations. The purpose of this paper is to introduce and illustrate an interactive cell formation method that can be used to design 'flexible' cells. Flexibility in this context refers to routing flexibility (i.e., the ability for the cellular system to process parts within multiple cells) and demand flexibility (i.e., the ability of the cell system to respond quickly to changes in part demand and part mix). Through an experimental analysis using multiple data sets, we also validate the procedure and provide guidelines for parameter settings depending upon the type of flexibility of interest to the user. Finally, trade-offs and interdependences between alternative types of flexibility in the context of cellular systems are illustrated.

Keywords: Dynamic, Flexibility, Cellular, Machines, Experimental analysis.

1. INTRODUCTION

Cellular manufacturing (CM), an application of group technology, entails the creation and operation of manufacturing cells. Each cell is dedicated to processing a specific set of part families. A manufacturing cell typically consists of several functionally dissimilar machines, whereas a part family consists of a set of parts with similar processing requirements. One of the first problems encountered in implementing CM is that of cell formation (CF). CF deals with the identification of the part family or families and associated machine groups that constitute each cell. Although the operational benefits of CM have been well-documented in the literature [1], it has also been argued that the implementation of cells could lead to a decrease in manufacturing flexibility [2]. The major difficulty with cells stems from potentially unstable machine utilizations due to dynamic and random variations in part demands [3]. This has led to some confusion as to the appropriateness of CM by industry users. On the one hand, companies would like to achieve the operational efficiencies through implementing CM systems, but, on the other hand, companies do not want to lose the strategic benefits of flexible operations. Further, as pointed out by Craig, et al. [4],flexibility is one of the critical dimensions of enhancing the competitiveness of organizations and hence the design of flexible' cells is an important issue [5].

This paper proposes a CF method that incorporates several flexibility criteria to guide the creation of flexible' cells. This approach is unique in several aspects. First, the cell system design generated is a function of the user priorities in terms of flexibility dimensions. This not only allows the user to incorporate preset user priorities but also allows the investigation of trade-offs between conflicting flexibility criteria. Secondly, although there is some prior research that has incorporated alternative process plans when identifying cell configurations (e.g, [6±11]), this is one of the first methods that focuses on part-operation requirements in creating cells. Most of the cell formation research to date (e.g., [12±20]) assumes that parts are processed on specific machine types and the assignment of operations to machines is determined a priori. However, to allow for flexibility in operation machine assignments, we explicitly incorporate this decision into our procedure. Thirdly, the method proposed in this research includes an explicit improvement stage where the user can attempt to modify the candidate design to increase alternative (or all) types of system flexibility.

The remainder of this paper is organized as follows. In Section 2 the relevant literature is reviewed and the flexibility criteria of interest for CM are introduced. Section 3describes the proposed CF procedure, and Section 4 presents an illustration of the methodology. Section 5 describes the experiment conducted to validate the proposed methodology and provides user guidelines for parameter settings depending on the flexibility criteria. Finally, the implications and conclusions of the research are discussed in Section 6.

2. RELEVANT LITERATURE

In recent years there has been a tremendous growth in the number of CF methods. The surge of interest in the area has been fueled not only by surveys that have shown the benefits of CMsystems [1] but also because there is substantial industry interest in implementing CM systems. Comprehensive reviews of CF can be found in [5, 21±24.

In the context of this paper, two papers on CF are the most relevant. Tilsley and Lewis [25] were the first to propose a CF method where routing flexibility was a primary consideration. They essentially propose a system of `cascade' cells that are created such that the more critical part families can be processed in more than one cell. Thus, machines required to process critical part families are allocated to more than one cell. Although the algorithmic details of the procedure are not provided, they do point out the importance of building in routing flexibility when machines within cells are subject to breakdowns. Machine downtime in a cell could be handled by having multiple machines of the same type in a cell or by routing operations performed on one machine in a cell to other machines in the same cell; however, these factors are not considered in their procedure.

Dahel and Smith [26] propose a procedure to create cells such that routing flexibility and cell independence could be simultaneously considered. They essentially formulate the CF problem as a multi-objective mathematical model that simultaneously attempts to create independent cells (by minimizing intercellular materials flows) and flexible cells (i.e., cells containing the largest variety of machine types). Their logic is that routing flexibility of the system is maximized when we can create such flexible cells.

In terms of flexibility dimesions, there has been a remarkable lack of interest in designing cells that can respond quickly to changes in the part demands (in terms of new part introduction and in terms of changes in volumes of current part). To address this issue, Vakharia, et al. [27] develop a framework and measures for different flexibility types relevant in the context of CM systems. These types are:

- machine type flexibility: the ability of the machines grouped into cells to process a large number of distinct operation types;
- routing flexibility: the ability of the cell system to process parts completely in multiple cells (referred to as process flexibility in [28]);
- part volume flexibility: the ability of the cell system to deal with volume changes in the current part mix; and
- part mix flexibility: the ability of the cell system to handle different product mixes with minimum disruption.

Of these flexibility types, routing, part volume, and part mix flexibilities are determined by the cell system design generated, whereas machine type flexibility is also a function of the technological constraints on the machines. Our primary objective in this paper is to consider all four types of flexbility in developing a CF method. This procedure is described in the next section.

3. FLEXIBLE CELL FORMATION (FCF) METHOD

An overview of the proposed FCF method is shown in Fig. 1. Phase I identifies the most economical set of machine types to process the required operations of the entire part set based on machine costs, capabilities, and capacities. Phase II assigns individual part-operations to individual machines with an objective of providing an assignment that will lead to minimum material handling cost in final system design. Balancing material handling costs, current processing requirements, and flexibility to adapt to changes, Phase III forms candidate cells. The flexibility of this cellular configuration is then evaluated phase.

	DESCRIPTION	USER-INPUTS
1.	Assign operations to machine types	Max usage of machs machine cost operation set& times
2.	Assign part ops to individual machines of each type	Part-operations set operations times
3	Assign individual machine to cells	Max machines cells number of cells desirability indexW1
4.	Design improvement and evalution	Improvement types volume flexibility routing flexibility evalution measures

Production planning in cellular manufacturing:

Formation of cells is an important aspect of cellular manufacturing systems. Once the cells are formed, production planning is the next core activity to realize the benefits of cells. Production planning is concerned with establishing production goals over the planning horizon. The main objective of production planning in any organization is to ensure that the desired products are manufactured at the right time, in the right quantities, meeting quality specifications at minimum cost. A lot of information is required to develop a production plan. This input can then be transformed, using planning tools and techniques, into desirable outputs, that is the production planning process can be conceived as a transformation process in an input-output system framework. Johnson and Montgomery (1974) advocated input-output concepts which are equally valid in a cellular manufacturing environment. These concepts are adopted here with suitable modifications where necessary.

Information required as an input to develop a production plan includes:

- forecasts of future demand;
- alternate process routes for each product/ component;

- Production standards such as setup information for each machine and variable processing time.
- the capacity of available resources including jigs, fixtures, pallets, material handling equipment and machine tools;
- current inventory levels and the backlog position for each product;
- current work-in-process;
- workforce levels;
- material availability;
- cost standards and selling prices;
- Management policies such as overtime, subcontracting and multiple shift operations.

Dynamic cellular manufacturing system design:

4. PROBLEM FORMULATION:

The proposed integrated CMS model comprises traditional cell formation problem linked to multi-period production planning and system reconfiguration. The system reconfiguration involves machines relocation in cells or it may also involve change in part process route from period to period. The traditional cell formation problem follows formation of part families, machines grouping in the form of cells and assignment of part families to cells. In multiperiod production planning variation in product mix and the part demand size are met through internal production, or subcontracting.

There are different machine types in the cells with multiple operational capabilities and limited capacity to process part families. Also, there are different part types with specific operations requirement and processing time. The proposed model assumes that a candidate part operation is processed internally considering production capacity or through subcontracting to satisfy the part demand. In the past a few authors [28, 29, 32, 34] addressed subcontracting/outsourcing, but only as a subset of the part demand size.

The proposed approach emphasizes on the flexibility in part operation processing by permitting it to be switched to different production modes (in-house production or subcontracting) considering production capacity shortage and/ or sudden machine breakdown.

The overall objective of the model is to minimize the machine constant cost, the machine operating cost, the system reconfiguration cost, the production cost, the subcontracting part operation cost, and the inter and intracellular material handling cost. A mixed-integer mathematical formulation for the CMS design is presented below.

3.1 Notations

(a) Index sets

P {p = 1, 2, 3,…, P.} Part types

Op {k = 1, 2, 3,…, Op.} Operation k of part type p

M {m = 1, 2, 3,…, M.} Machine types

C {c = 1, 2, 3,…, C.} Manufacturing cells

T {t = 1, 2, 3,…, T.} Time periods

(b) Model parameters

Amc(t) Number of machine type m available in cell c at time period t

BuUpper cell size limit

BLLower cell size limit

DP(t) Demand for part type p at time period t

IEp Intercellular material handling cost per part type p

IAp Intracellular material handling cost per part type p

tkpmTime required to perform operation

k(k = 1,…,Op) of part type p (p = 1,…,P) on machine type m (m =1,…,M)

Xm Amortized cost of machine type m per period

βmOperating cost per hour of machine type m

δm Relocation cost of machine type m including installing, shifting

Tm Capacity of each machine type m in hours

Okp Subcontracting cost of operations k of part type p

μ**kp** Internal manufacturing cost of operation k of part type p

5. DISTINGUISHING PROPERTIES OF THE PROPOSED CMS MODEL

Production flexibility: The model is designed such that it can be set to different levels of manufacturing mode (internal production or subcontracting part operation) considering internal production capacity to satisfy demand requirements in the dynamic condition. The proposed model offers more flexibility in production planning that can be achieved by producing parts within the machine capacity limit of the manufacturing system. It is seldom noticed, the internal resource does not satisfy the part demand within the available machine capacity limits; however if it happens so/or during machine breakdown, parts operation can be subcontracted to satisfy the demand requirements.

Dynamic system reconfiguration and machine procurement: The CMS model might not be optimal for dynamic deterministic demand in terms of overall cost for future planning, therefore system needs to be reconfigured in each period owing to variation in part type and their lot size. The Proposed model allows the formation of the best configuration within each planning period in terms of the type and number of machines assigned to cells and part routings. The system eliminates procurement of extra machines when inter-cell move cost is less than machine procurement cost. This is achieved when machines are relocated and new process routings are chosen based on tradeoff in cells and minimum machine operating time. The strength of this CMS model to deal with variation in part mix demand is improved by the fact that new machine can be brought in through machine procurement to increase the internal production capacity.

Cell formation with flexible resource routing: Multiple part routings are an important characteristic of the model. The part routing is a set of possible machines that can be used to perform the required operation on a part. With multifunctional machines and multiple copies of each machine type allowed in the system, the presence of multiple routing is important since this gives more flexibility in deciding upon the CMS configurations. In this research, the model permits the system to select the best route instead of the user specifying predetermined routes. The model permits all the possible routes to coexist; and more than one route can be chosen to make a part considering resources availability (internal and subcontracting part operation process).

The simulated annealing based genetic algorithm:

The traditional genetic algorithm suffers from premature convergence and affects the quality of solution. The traditional mechanism of genetic algorithm set off the pattern of effective solutions higher than the average in next generation. It strict the hunting zone and rapidly converge the population, does not necessarily achieve global optimum solution. In order to explore the solution region efficiently and to expedite the solution search space, thesimulated annealing strategy is combined in the genetic algorithm.

The simulated annealing based genetic algorithm (SAGA) incorporates the best features of genetic algorithm (searching larger regions of solution spaces) and simulated annealing (refining exhaustive solution of local region). The basic idea is to use the genetic operators of genetic algorithm to quickly converge the search to near-global minima/maxima, which will further be refined to a nearoptimum solution by using simulated annealing process. Recent work on genetic algorithm-oriented hybrids is the simulated annealing genetic algorithm (SAGA) proposed by Brown et al [41.

The proposed algorithm imparts synergy effect between the SA and GA by presenting a hybrid algorithm employing the SA. In this algorithm, the initial solution of SA comes from the evolution of GA. The solution obtained by sampling of SA serves as the initial individual of GA so that a hybrid search is made possible. The proposed hybrid SAGA algorithm is applied for the considered DCMS problem with a matrix schema and the novel operators are presented in following sections.

Solution representation schema:

In the solution representation schema, two matrices [PMpk] and [PCpk] are employed in each period segment of the planning horizon. The matrix [PMpk] denotes the allocation of part-operation to machine and the matrix [PCpk] denotes the allocation of part-operation to cell. PMpk is the machine performs operation k of part type p, where PMpk 2 /kpand /kp ¼ m akpm ¼ 1 . Also, PCpk is the cell allocated with operation k of part type p, where 1 B PCpk B C.

6. Conclusion and future research direction

This paper presents a novel integrated mathematical model for design of cellular manufacturing system considering dynamic production and multi-period production planning.

The integrated model in this research incorporates the traditional cell formation problem bridged with the machine allocation problem, multiple part process routing problem and system reconfiguration problem. The proposed model offers flexibility in production planning (production/subcontracting) that can be achieved by producing product mixes at each period of planning horizon considering production capacity shortage.

The algorithm aggregates resources into different manufacturing cells based on selected optimal process route from user specifying multiple routes. The results obtained show that the co-existence of multiple possible resource routings (in-house production/subcontracting) builds up flexibility in production and it is a tangible advantage during unexpected machine breakdown and production capacity shortage occurring in real world.

The model is computable with single part routing as well as multiple part routings. The proposed approach can also be readily used where limits are imposed on the cell sizes and/or number of cells. The proposed CMS model has been attempted using a simulated annealing based genetic algorithm. The algorithm uses simulated annealing strategy and genetic operators to avoid premature convergence. The algorithm improves intensification, diversification and increases possibility of achieving near-optimum solutions.

The research reported in this paper is a part of the major research project on robust design of CMS. The authors are working to further improve the mathematical model for design of CMS incorporating more real world aspects of the manufacturing system, such as lot splitting and machine adjacency requirements to widen its area and make the study more useful.

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