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Design of robust cellular manufacturing system for dynamic part population considering multiple processing routes using genetic algorithm

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ABSTRACT

In this paper, a comprehensive mathematical model is proposed for designing robust machine cells for dynamic part production. The proposed model incorporates machine cell configuration design problem bridged with the machines allocation problem, the dynamic production problem and the part routing problem. Multiple process plans for each part and alternatives process routes for each of those plans are considered. The design of robust cell configurations is based on the selected best part process route from user specified multiple process routes for each part type considering average product demand during the planning horizon. The dynamic part demand can be satisfied from internal production having limited capacity and/or through subcontracting part operation without affecting the machine cell configuration in successive period segments of the planning horizon. A genetic algorithm based heuristic is proposed to solve the model for minimization of the overall cost considering various manufacturing aspects such as production volume, multiple process route, machine capacity, material handling and subcontracting part operation.

1. Introduction

Product diversity, short product life cycle and intense pressure to increase the productivity, etc. lead to global competition among manufactures. A wide product variety as quickly as possible to cater the need of customer with low production cost and maintained quality level signify a capable production system. The traditional manufacturing systems such as job shop and flow lines do not satisfy such requisite.

In job shops, products are manufactured in different shops hence jobs spend 95% of the time in non productive activity; much of the time is spent in waiting in queue and the remaining 5% is split between lot setup and processing [1].

In a flow line manufacturing, machines are arranged according to operation sequence of product. It is suitable for high production volume. A major limitation of flow line is the lack of flexibility to produce product for which they are not designed. This is because the system involves specialized machines to perform limited operations with no chance of reconfiguration.

The changes in product design and demand fluctuation often require reconfigurable manufacturing systems. An innovative realistic manufacturing methodology is required to suppress the demerits of the traditional manufacturing systems in practice.

The Group Technology (GT) is an innovative manufacturing strategy that sorts out similar parts and groups them together into families to take advantage of their similarities in design and manufacturing. The GT build on the concept that single solution can be found to solve a set of problems sharing common principle and tasks, so that time and effort can be saved [2].

The cellular manufacturing (CM) is an application of Group Technology. It takes advantage of the similarity among parts, through standardization and common processing. The CM groups machines into machine cells and parts into part families [3]. The CM suppresses the demerits of job shops and flow lines by increasing the flexibility and variety in production. The major advantage is in terms of material flow which is significantly improved, with reduction in inventory level and distance traveled by the material. This finally results in reduction in cumulative lead time.

Various approaches ranging from simple to sophisticated have been suggested for the formation of manufacturing cells and part

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families. The simple technique usually manipulates part machine matrices. The sophisticated ones can handle many constraints, such as maximum cell size, demand size for different products, number of cells and set up cost [4]. Most of the approaches assume that part demand stays constant over long periods of time [5]. In recent decades, a few studies have been reported considering today's market based dynamic environment [6–9]. A brief review in this regard has been reported in literature [10,11].

The dynamic conditions prevail in the real world manufacturing environment. Thus the design of CMS, which involves allocation of resources in different manufacturing cells and formation of part families, is difficult. This is due to the fact that the variable product demand size and the machine breakdown affect the performance of cellular manufacturing system design from one period to other. Designers often need to obtain a robust manufacturing system design to handle changes in product demand size, processing times and equipment failure & repairs without any interruption in the production system.

This paper suggests a robust model for dynamic production in a cellular manufacturing environment. Multiple process plans for each part and alternatives process routes for each of them are considered. The dynamic part demand can be satisfied from internal production or through subcontracting part operation without affecting the machine cell configuration in successive period segments of the planning horizon. A Genetic algorithm based heuristic is applied to optimize the number of machines in different manufacturing cells in a manufacturing system producing multiple products. The main constraints are the machine-time capacity and the maximum cell size.

The computational performance of the proposed approach has been evaluated by testing the algorithm on a few test benchmark problem collected from literature. The robust manufacturing cell configuration so obtained can effectively cope up with the product demand variability, over various periods of planning horizon without production interruption and machine relocation in comparison with adaptive cell configuration of the problems tested.

2. Literature review

Different approaches have been proposed to solve PF/MC problems over the decades [2,12–17]. The authors presented numerous formulations and solution strategies to attempt the problem. Wemmerlov and Hyer [18] reviewed over 70 research contributions and classified them based on descriptive and analytical procedures for the part family/machine group identification problem. In another effort Joines et al. [19] reviewed and classified more than 230 methodologies for forming part families and machine cells. Individual techniques are aggregated into methodological groups including array based clustering, hierarchical clustering, non-hierarchical clustering, graph theoretic approach, artificial intelligence, math programming, and other heuristic approaches.

The majority of PF/MC formation methods presume a stable part demand and product mix. In reality, the demand for the product varies over its life cycle, new products are introduced, and the production of older products is discontinued. Hence the performance of CMS is adversely influenced by varying value of part demands and product mix. The main input to the PF/MC formation is machine part combinations in cells which represents processing requirements of parts in a given products mix. Hence the product mix variation affects the cell structure in terms of machine part combination and thus performance of the CMS [20].

Rosenblatt and Lee [21] developed a robustness approach to deal with uncertain product demand for single period plant layout. They considered a stochastic environment in which exact values of probability of various scenarios are unknown. The performance of robust of layout is measured in terms of flexibility to handle various scenarios.

Seifoddini [22] presented a probabilistic machine cell formation model to deal with the random nature of product demand for a single period. The machine cell formation is accomplished by employing the similarity coefficient method. The inter-cell material handling cost is used as criteria for selecting the best machine cell configuration.

Vakharia and Kaku [23] incorporated long-term demand changes into their 0–1 mathematical programming cell design method by altering parts in part families to regain the benefits of cellular manufacturing system. Similarly, new parts are allocated to existing manufacturing cells. Hence, machine cells composition remains unchanged in their multi-period design.

Harhalakis et al. [24] obtained robust cellular configuration using mathematical programming based on the expected values that would be effective over the certain ranges of demand during multiple periods. Once the cells are designed they are expected to remain unchanged during the multi period horizon.

Seifoddini and Djassemi [25] carried out sensitivity analysis on the performance of the CMS by considering the product mix variations. The simulation results show that changes in the product mix may lead to the deterioration of the performance of the system. The determination of the sensitivity of a cellular manufacturing system to product mix variation is an important step in the decision making about conversion from job shop to cellular manufacturing. The performance measures used in this analysis are the mean flow time and the work-in-process inventory.

Askin et al. [26] proposed algorithm based cell formation method to deal with variation in product mix. The part operation processing has been considered feasible on more than one machine type. Subsequent phases allocate the part operation to specific machines, identify manufacturing cell, and improve the cell design. The machine cells once designed are expected to remain unchanged during the planning horizon.

Wicks and Reasor [7] compared the multi period CMS design method with a static CM approach using an illustrative problem. In the static method the cell is designed using the first-period demand only and there are no further rearrangements. When the part mix changes, the new parts are introduced into the existing CMS based on minimizing the inter-cell transfers of parts. Results show that the multi-period approach (adaptive design) involving a planned rearrangement of cells performs better than the static situation.

Mungwattana [8] designed the CMS for dynamic and stochastic production requirements, employing routing flexibility. In this work, the differences between robust design and adaptive design strategies of cellular manufacturing systems are described.

Arzi et al. [27] proposed a new methodology for the design of CMS working under lumpy demand conditions. Production capacity shortages or machines idleness are observed due to stochastic and unstable external demands. The manufacturing cell reconfiguration is avoided by reducing the variability in the capacity requirements using an appropriate product mix in each period.

Kouvelis et al. [28] proposed an algorithm for design of robust layout in cellular manufacturing system. The approach is applicable to single and multi period problems involving variable product mix and demand size. The algorithms, executed in a heuristic fashion, can be effectively used for layout design of large size manufacturing systems.

Cao and Chen [29] presented an optimization model integrating cell formation and part allocation with product demand size expressed in number of probabilistic scenario to generate a robust system configuration. Single process plan for each part type is considered. The objective is to minimize the material handling cost and machine cost incurred in the system. A tabu search based heuristic algorithm is proposed to solve the problem.