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A comprehensive mathematical model for the design of cellular manufacturing systems

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Abstract

The design of cellular manufacturing systems (CMS) involves many structural and operational issues. One of the important design steps is the formation of part families and machine cells. In this paper, a comprehensive mathematical model for the design of CMS based on tooling requirements of the parts and tooling available on the machines is proposed. The model incorporates dynamic cell configuration, alternative routings, lot splitting, sequence of operations, multiple units of identical machines, machine capacity, workload balancing among cells, operation cost, cost of subcontracting part processing, tool consumption cost, setup cost, cell size limits, and machine adjacency constraints. Numerical examples are presented to demonstrate the model and its potential benefits.

Keywords: Cellular manufacturing; Dynamic cell configuration; Alternate routings; Lot splitting; Workload balancing; Integer programming

1. Introduction

A cellular manufacturing system (CMS) is a production approach aimed at increasing production efficiency and system flexibility by utilizing the process similarities of the parts. It involves grouping similar parts into part families and the corresponding machines into machine cells. This results in the organization of production systems into relatively self-contained and self-regulated groups of machines such that each group of machines undertake an efficient production of a family of parts. Such decomposition of the plant operations into subsystems may often lead to reduced paper work, reduced production lead time, reduced work-in-process, reduced labor, better supervisory control, reduced tooling, reduced setup time, reduced delivery time, reduced rework and scrap materials, and improved quality (Wemmerlöv and Johnson, 1997).

In the last three decades, research in CMS has been extensive and literature in this area is abundant. Comprehensive summaries and taxonomies of studies devoted to part-machine grouping problems were presented by Wemmerlöv and Hyer (1986), Kusiak (1987), Selim et al. (1998), and Mansouri et al. (2000). Methods for part family/machine cell formation can be classified as

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design-oriented or production-oriented. Design-oriented approaches group parts into families based on similar design features. An overview of design-oriented approaches based on classification and coding was presented by Askin and Vakharia (1990). Production-oriented techniques are for aggregating parts requiring similar processing. These approaches can be further classified into cluster analysis, graph partitioning, mathematical programming, artificial intelligence (AI) based approaches, and heuristics (Greene and Sadowski, 1984; Joines et al., 1996).

Mathematical programming is widely used for modeling CMS problems. The objective of the mathematical programming model is often to maximize the total sum of similarities of parts in each cell, or to minimize inter-cell material handling cost. Purcheck (1974) applied linear programming techniques to a group technology problem. Kusiak (1987) proposed the generalized *p*-median model considering the presence of alternative routings. Shtub (1989) used the same approach and reformulated the problem as a generalized assignment problem. Wei and Gaither (1990) developed a 0–1 programming cell formation model to minimize bottleneck cost, maximize average cell utilization, and minimize intra-cell and inter-cell load imbalances. The bottleneck cost is related to the processing of bottleneck parts. Rajamani et al. (1990) proposed three integer programming models to consider budget and machine capacity constraints as well as alternative process plans. Askin and Chiu (1990) proposed a cost-based mathematical formulation and a heuristic graph partitioning procedure for cell formation. Shafer and Rogers (1991) applied a goal programming method to solving CMS problems for different system reconfiguration situations: setting up a new system and purchasing all new equipment, reorganizing the system using only existing equipment, and reorganizing the system using existing and some new equipment. Shafer et al. (1992) presented a mathematical programming model to address the issues related to exceptional elements. Heragu and Chen (1998) developed a mathematical programming model for cell formation and used Benders' decomposition to solve the problem.

Various methods have been proposed for cell formation incorporating several system features simultaneously. A list of these features is given in Table 1. A sample of 19 recently published articles and the corresponding system features considered in these articles are given in Table 2. The model presented in this paper provides a larger coverage of the attributes than the individual papers. A wider range of input data and cell formation criteria are incorporated than many of the models reviewed in Mansouri et al. (2000). The rest of this paper is organized as follows. Detailed descriptions of the problem and the proposed model are given in Section 2. Numerical examples are presented in Section 3 to illustrate the proposed model. Discussion and conclusions are presented in Section 4.

Table 1
List of manufacturing attributes

1. Alternative routing
(a) Selecting the best route
(b) Allowing alternative routing coexist
2. Demand fluctuation
(a) Deterministic
(b) Probabilistic
3. Dynamic cell reconfiguration
4. Workload balancing
(a) Inter-cell workload
(b) Intra-cell workload
5. Lot-splitting
6. Types of tools required by a part
7. Types of tools available on a machine
8. Machine proximity constraint
(a) Separation constraint
(b) Collocation constraint
9. Sequence of operation
(a) Used as input for determine magnitude of material flow
(b) Used as similarity measure between parts
10. Setup cost/time
(a) Setup cost
(b) Setup time
11. Cell/part family size constraint
(a) Cell size constraint
(b) Part family size constraint
12. Movement of parts (material handling cost)
(a) Inter-cell movement
(b) Intra-cell movement
13. Facility layout
(a) Inter-cell layout
(b) Intra-cell layout
14. Operator allocation
15. Machine capacity
16. Identical machines
(a) Within a cell
(b) In the entire system
17. Machine investment cost
18. Subcontracting cost
19. Tool consumption cost
20. Unit operation time
21. Operation cost