Computers & Industrial Engineering 85 (2015) 346–358

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Comparison of layered cellular manufacturing system design approaches

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ARTICLE INFO

Article history:
Received 16 May 2014
Received in revised form 27 December 2014
Accepted 23 February 2015
Available online 16 March 2015

Keywords:
Cellular manufacturing
Layered cellular design
Simulation
Stochastic demand
Mathematical modeling

ABSTRACT

In this study, a mathematical programming approach is proposed to design a layered cellular manufacturing system in highly fluctuated demand environment. A mathematical model is developed to create dedicated, shared and remainder cells with the objective of minimizing the number of cells. In contrast with classical cellular manufacturing systems, in layered cellular systems, some cells can serve to multiple part families. A five-step hierarchical methodology is employed: (1) formation of part families, (2) calculation of expected cell utilizations and demand coverage probabilities, (3) specification cell types as dedicated, shared, and remainder cells, (4) simulation of proposed layered systems to evaluate their performance with respect to average flowtime and work-in-process inventory, and (5) statistical analysis to find the best layered cellular design among alternatives. It is found that designs with higher number of part families tend to have less number of machines. Similar results are also observed with respect to average flowtime and work-in-process inventory measures. The results are also compared with a heuristic approach from the literature. None of the approaches is dominant with respect to all of the performance measures. Mathematical modeling approach performs better in terms of number of machines for most of the alternative designs. However, heuristic approach yields better average flowtime and work-in-process inventory for most of the designs.

1. Introduction

Manufacturing systems are classified into four categories based on their layouts: cellular manufacturing layout, product layout, process layout, and fixed layout. Fig. 1 shows these layouts in the context of product variety and product volume. As production volume increases and product variety decreases, product layout becomes more suitable for the manufacturing systems. This layout type yields lower product flowtime and work-in-process (WIP) inventory. As product variety increases and production volume decreases, process layout becomes a better option due to its flexibility. Cellular manufacturing is a solution where production volume and product variety are moderate. In a fixed layout, as the name implies, the product is kept in a location and workers and machines are brought to the product to perform the required operations.

In classical cellular manufacturing systems, each product family is assigned to its own dedicated cell(s) which ideally has all of the machines, tools and manpower needed. These systems work efficiently in terms of machine and cell utilization when the demand is steady and predictable. Fig. 2 represents an example of a classical cellular manufacturing system with four part families and their dedicated cells.

However, when the demand significantly fluctuates, performing operations in only dedicated cells may not yield the same efficiency. When the demand is lower than the expected amount, cells are underutilized. On the other hand, when demand is higher, dedicated cells will not be able to process all of the products on time. In order to deal with this fluctuating demand, Süer, Huang, and Maddisetty (2010) proposed a layered system which consists of dedicated, shared, and remainder cells. Dedicated cells are defined the same as in classical manufacturing systems; dedicated cells process only their assigned product families. Shared cells process two families, and remainder cells process more than two families. Hence, a product family can be processed in dedicated cells, shared cells, and remainder cells at the same time. Fig. 3 presents an example of the layered cellular system. In their study, they used a heuristic procedure to create dedicated, shared and remainder cells considering expected utilization of cells, demand coverage probabilities and the similarities among part families. Their study showed that, in high demand fluctuation case, the layered design yields better results than the classical design in terms of WIP and average flowtime. On the other hand, the classical design was

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http://dx.doi.org/10.1016/j.cie.2015.02.021
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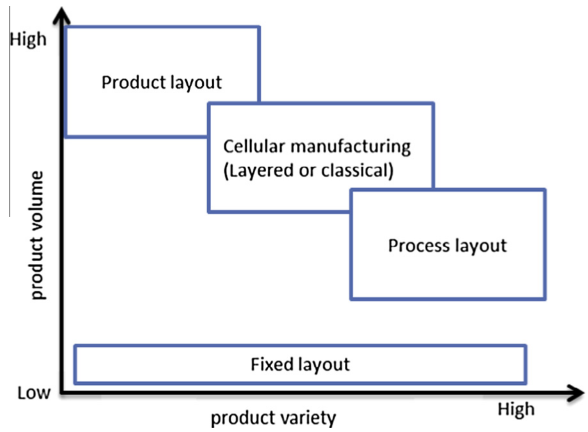

Fig. 1. Manufacturing systems classification (adopted from Süer et al., 2010).

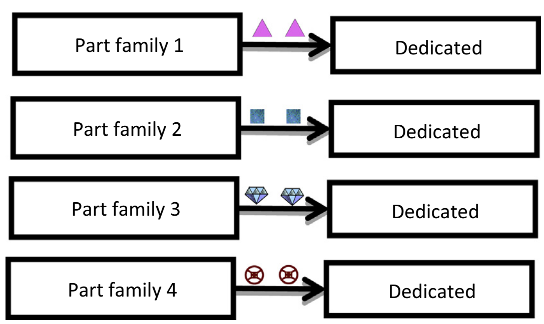

Fig. 2. A classical cellular manufacturing system.

better in terms of number of machines. However, in low demand fluctuation case, the classical design performed better than the layered design at all performance measures. In this study, a mathematical model is proposed to create a layered cellular manufacturing system with the objective of minimizing the number of cells in highly fluctuating stochastic demand environment. The results are then compared with the study of Süer et al. (2010).

The rest of the paper is organized as follows. Cellular manufacturing design literature is presented in Section 2. Section 3 explains the manufacturing system studied. Methodology followed is described in Section 4. The results of the proposed mathematical and simulation models are presented in Section 5. The results are then compared with the study of Süer et al. (2010) in Section 6. Section 7 discusses the findings and future directions from this research.

2. Literature review

Various types of cellular manufacturing systems have been proposed in the literature. Examples include dynamic cellular manufacturing (Rheault, Drolet, & Abdulnour, 1996), virtual cellular manufacturing, holonic manufacturing (Nomden, Slomp, & Suresh, 2005), fractal cellular manufacturing (Montreuil, Venkatadri, & Rardin, 1999), layered cellular manufacturing with dedicated, shared and remainder cells (Süer et al., 2010). In a virtual manufacturing cell, a group of machines and/or operators are assigned to produce a part family, but machines are not physically put together. Dynamic cells are introduced to deal with turbulent environment and the physical locations of the machines may be changed anytime as needed to respond to the fluctuation in the demand (Rheault et al., 1996). In fractal cell configuration, cells contain workstations which have two or three machines. Then, a few of these workstations form similar fractal cells that have the ability to manufacture most or all of the product families (Montreuil et al., 1999). All of the fractal cells can be identical. However, some workstations can be shared by two different fractal cells to avoid duplicate machines. Süer et al. (2010) made a hierarchical classification of manufacturing cells as dedicated, shared and remainder cells. Dedicated cells are aimed to process only one part family, whereas shared cells have the ability to process two part families and remainder cells can process more than two part families. Cellular manufacturing systems are categorized also as single-stage and multi-stage cellular manufacturing systems (Süer, Saiz, Dagli, & Gonzalez, 1995). In single-stage cells, all operations are completed in one cell. According to Süer et al. (1995), if the output of a cell is used as an input by another cell, i.e., more than one cell is involved in finishing the end product; these cells are called connected cells. In connected cells, operations are completed in different cells located in multiple stages (Süer & Lobo, 2013). Another categorization was also introduced by Süer and Bera (1998) considering the involvement of labor force in the process. In this regard, manufacturing cells were categorized as labor or machine-intensive cells. In machine-intensive cells most or all of the work is done by machines and the responsibilities of the workers are limited to loading, unloading, transferring the parts, etc. In labor-intensive cells, workers are involved more in performing the operations. In labor-intensive cells, processing times show more variability due to variations in the skill and experience of the workers.

Mathematical models are widely used in deterministic cellular manufacturing literature for cell design. Purcheck proposed a classification for cell formation problems (Purcheck, 1974). Kusiak (1987) developed integer programming models for part families

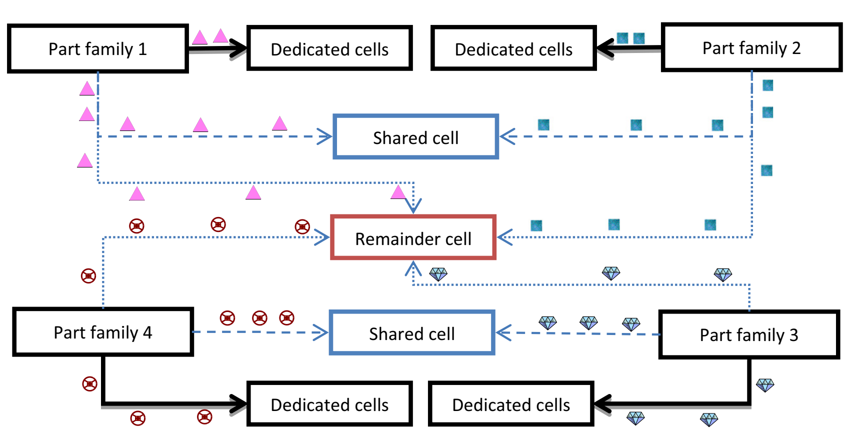

Fig. 3. A layered cellular manufacturing system.