Applied Mathematical Modelling 40 (2016) 169–191

Contents lists available at ScienceDirect

Applied Mathematical Modelling

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

# A robust optimization approach for an integrated dynamic cellular manufacturing system and production planning with unreliable machines

M. Sakhaii [a,*], R. Tavakkoli-Moghaddam [b,c], M. Bagheri [d], B. Vatani [e]

[a] Department of Industrial & Systems Engineering, University of Ohio, Athens, OH, USA
[b] School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran
[c] Research Center for Organizational Processes Improvement, Sari, Iran
[d] Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran
[e] Department of Electrical Engineering, University of North Carolina at Charlotte, Charlotte, NC, USA

ARTICLE INFO

*Article history:*
Received 8 June 2013
Received in revised form 20 April 2015
Accepted 14 May 2015
Available online 5 June 2015

*Keywords:*
Robust optimization
Dynamic cellular manufacturing system
Production planning
Uncertainty
Machine reliability
Operator assignment

ABSTRACT

In this study, a robust optimization approach is developed for a new integrated mixed-integer linear programming (MILP) model to solve a dynamic cellular manufacturing system (DCMS) with unreliable machines and a production planning problem simultaneously. This model is incorporated with dynamic cell formation, inter-cell layout, machine reliability, operator assignment, alternative process routings and production planning concepts. To cope with the parts processing time uncertainty, a robust optimization approach immunized against even worst-case is adopted. In fact, this approach enables the system's planner to assess different levels of uncertainty and conservation throughout planning horizon. This study minimizes the costs of machine breakdown and relocation, operator training and hiring, inter-intra cell part trip, and shortage and inventory. To verify the performance of the presented model and proposed approach, some numerical examples are solved in hypothetical limits using the CPLEX solver. The experimental results demonstrate the validity of the presented model and the performance of the developed approach in finding an optimal solution. Finally, the conclusion is presented.


## 1. Introduction

Cellular manufacturing (CM) concept as an application of group technology philosophy in industrial environments uses adjacency among the parts features to reduce parts defect rates, throughput times, factory space requirements, material trips and system setup times and costs. On the other hand, the main goal of production planning (PP) as a capacity planning tool is to reduce the inventory and shortage levels. In fact, PP is the means by which we prepare our production quantities. Due to nowadays competitive manufacturing environment, having more efficiency and productivity is become a vital concern for industry owners, to produce with the lowest level of cost and casualties as well as the highest level of flexibility. Therefore, in recent years most industries show great inclination to cellular manufacturing systems (CMSs). A CMS design consists of four important decisions: cell formation (CF), group layout (GL), group scheduling (GS) and resource allocation (RA) assigning various resources (e.g., operators, equipment and materials) [1–3]. In manufacturing environments, these

* Corresponding author.
*E-mail address:* mandana.sakhaii@gmail.com (M. Sakhaii).

http://dx.doi.org/10.1016/j.apm.2015.05.005
0307-904X/

decisions are inter-linked. Therefore, the need arises to develop models considering them as an integrated whole. Indeed, it cannot be guaranteed that optimal decisions obtained from a problem that only models with one of the aforementioned factors (i.e., CF, GL, RA and production planning) will be optimal for another problem, separately. Indeed, a real industrial environment comprises all of these factors together. For instance, the obtained solutions satisfying only limitations of the CF problem cannot satisfy the limitations of a problem integrated all factors. Then, the final design may not be efficient and optimal. Consequently, in order to have a model whose decisions are comparable with practical decisions, a comprehensive model is necessary.

Most of the previous studies usually concentrate only on CF decision. A comprehensive review of CF related studies can be found in [4–8].

There have been some studies that concentrate on GL. Rosenblatt [9] investigated a dynamic layout and illustrated that generating a static configuration at random is not effective. Wang et al. [10] developed a model in CMS, which considers demand changes over the product life cycle. They minimized the total material handling cost and solved inter and intra-cell facility layout problems, concurrently, using a simulated annealing (SA) algorithm. Solimanpur et al. [11] proposed an inter-cell layout problem in cellular manufacturing. In their study, the problem is modeled as a quadratic assignment problem and then an ant colony optimization (ACO) algorithm is developed to solve the proposed model. Tavakkoli-Moghaddam et al. [12] formulated a facility layout model in a CMS by considering stochastic demands, in which the objective function is to minimize inter and intra-cell material handling costs in both inter–intra cell layout problems, concurrently.

There are some studies in the literature integrate CF and GL decisions together. Paydar et al. [13] developed a solution to solve cell formation and layout of machines within each cell problem, concurrently, under the assumption that a number of cells are known in advance. They treated CM as a multiple departures single destination multiple traveling salesman problem and a solution methodology based on SA is proposed to solve the formulated model. Kia et al. [2] proposed an integrated CF and GL model, in which the multi-rows layout utilization to locate machines in the cells configured with flexible shapes and some design features is considered.

As mentioned previously, one of the decisions in developing a CMS is considering resource allocation (e.g., operator allocation) that has rarely been considered in CM models; usually job waiting occurs due to the non-availability of machines and/or operators. Therefore, operator allocation to machines can play a key role in the CMS efficiency. Aryanezhad et al. [14] proposed a dynamic cell formation and operator assignment problem. They considered alternative process routings, machine flexibility and workers promotion from one skill level to another in which the objective function is to minimize production cost, inter-cell material cost, machine costs, hiring, firing, training and salary costs. Ghotboddini et al. [15] presented a multi-objective mixed-integer model for the DCMS, which considers cell formation, simultaneously, with labor assignment to minimize the reassignment cost of human resource, over time cost of equipment and labors, and maximize the utilization rate of human resource. Then, they solve their model with the Benders' decomposition approach.

One of the other important factors in designing CMS is the system reliability. This factor can affect the system total efficiency strictly. Machine breakdowns result in higher production costs, longer production period and other manufacturing problems. A few studies have been developed to overcome machine breakdown challenges in the CMS design. Das et al. [16] developed the CMS design to minimize the total system costs and maximize the machine reliabilities along the selected processing routes, which provides a flexible routing that ensures a high overall performance of the CMS. Chung et al. [17] proposed an efficient tabu search (TS) algorithm based on a similarity coefficient to solve the CF problem with alternative process routings and machine reliability considerations. Rafiee et al. [18] proposed an integrated cell formation and inventory lot sizing problem to minimize some CMS costs. Moreover the process deterioration and machine breakdowns are considered to make the model more practical and applicable.

In most studies, researchers have developed CMS problems under a static environment, in which the product mix and demand rate are constant and known in one single period. However, considering a dynamic environment is more realistic. In dynamic environments, a multi-period horizon is considered where the number of the product mix-set and demand rate are different in each period. Therefore, the best cell configuration for one period may not be optimal for other periods [19]. See [20] and [21] as recent surveys. A dynamic cell formation problem and production planning are strongly inter-linked and should not be solved separately and sequentially for following reasons:

- In the real industrial environment, the production quantity usually is not equal to the demand quantity in each planning horizon, and it may be gratified from inventory.
- Production planning decisions should ascertain the amount of production to determine the machines type and number that should be installed in each cell. On the other hand, due to the capacity consideration number of different machines to be installed in each cell should be known in turn to determine the amount of production [22].

The usual constraints employed are: (1) inventory balance equations for making the inventory and/or shortages balanced with those from the previous period, production quantity, and the demand quantity and (2) capacity constraints that ensure the total workload for each resource (e.g., labor and machine) [23].

There are some studies in literature, in which the CMS and production planning are considered simultaneously to reach an efficient production plan. Ah Kioon et al. [24] developed a model consisted of cell formation, system reconfiguration, multiple process routings, production planning, machine capacities and availabilities. Safaei and Tavakkoli-Moghaddam [25]