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Worker assignment and production planning with learning and forgetting in manufacturing cells by hybrid bacteria foraging algorithm

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ABSTRACT

We consider a joint decision model of worker assignment and production planning in a dynamic cellular manufacturing system of fiber connector manufacturing industry. On one hand, due to the learning and forgetting effects of workers, the production rate of each workstation will often change. Thus, the bottleneck workstation may transfer to another one in the next period. It is worthwhile to reassign multi-skilled workers such that the production rate of bottleneck workstation may increase. On the other hand, because of the limited production capacity and variety of orders, late delivery or production in advance often occurs at each period. The parts with operational sequence need to be dispatched to the desirable cells for processing. The objective is to minimize backorder cost and holding cost of inventory. To solve this complicated problem, we propose an efficient hybrid bacteria foraging algorithm (HBFA) with elaborately designed solution representation and bacteria evolution operators. A two-phase based heuristic is embedded in the HBFA to generate a high quality initial solution for further search. We tested our algorithm using randomly generated instances by comparing with the original bacteria foraging algorithm (OBFA), discrete bacteria foraging algorithm (DBFA), hybrid genetic algorithm (HGA) and hybrid simulated annealing (HSA). Our results show that the proposed HBFA has better performance than the four compared algorithms with the same running time.

1. Introduction

Cellular Manufacturing System (CMS) has emerged to cope with the production environments with demands for mid-volume and mid-variety product mixes. It is a hybrid system that links the advantages of job shops (flexibility in producing a wide variety of products) and flow lines (efficient flow and high production rate). The CMS in labor intensive industries has been implemented with favorable results, including better utilization of workforce, production efficiency, reduction of inventory and delay. All of these benefits give rise to a decrease in operational costs. In a dynamic environment, a multi-period planning horizon should be considered where each period has different product mix and demand requirements. Therefore, the worker configuration and product portfolio in a period may not be optimal and efficient for the next period. There are two important issues for dynamic CMS in labor intensive industries. One issue is the worker flexibility and assignment/reassignment, and the other issue is production planning.

For the first issue, workers in the manufacturing environment must constantly learn new skills, technology and processes in order to keep up with the move toward rapid innovations of products and production. Skill levels of the workers improve through practice or deteriorate if out of practice in a multi-period analysis. Due to the learning and forgetting effects of workers, the production rate of each workstation will often change. Thus, the bottleneck workstation with the least production rate may transfer to another one in the next period. Consequently, it is essential and worthwhile to reassign workers to increase the production rate of bottleneck workstation in each cell, and hence improve the efficiency of the CMS.

For the second issue, with shorter product life cycles and increasing diverse demands of customers, there has been a shift from static environment to dynamic environment. In static

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environment, the system runs for a single time period with known and constant product mix and demand, while in dynamic environment, the system operates with a different product mix and demand requirements in each period. Due to the limited production capacity (related to worker assignment) and variety of orders in dynamic CMS, late delivery or production in advance often occurs at each period. Shop floor managers should make appropriate planning decisions for all types of products to smooth the production loads, so that the backorder cost and holding cost of inventory can be reduced effectively.

Due to the high complexity of dynamic CMS in labor intensive setting, the above two issues are normally studied independently or sequentially, in spite of the inter-relationship between them. Worker assignment determines the production capacity of the cells and affects production planning of all products in all periods. In contrast, the production quantities in each planning period also affect the individual and number of workers to be assigned to all cells. The optimization domain will be restrained and the optimal benefits of the dynamic CMS may not be fully realized when making decision on one issue after another. In addition, to the best of our knowledge, there are few studies considering learning and forgetting effects during multi-skilled workforce reassignment in this kind of problem. Therefore, simultaneous optimization of worker assignment and production planning becomes a very important area of research in minimizing the operational costs including backorder cost and holding cost.

Ever since Passino (2002) invented the bacteria foraging algorithm (BFA), it has shown a high level optimization capability in dealing with very complicated NP-hard problems without significantly increasing the computational time. These problems involve portfolio asset selection in financial field (Mishra, Panda, & Majhi, 2014), bidding strategy of a supplier (Jain, Srivastava, Singh, & Srivastava, 2015), margin of loading in multimachine power system (Tripathy & Mishra, 2015), design strategy of stacked patch resonator (Jain, 2015), workspace volume of a three-revolute manipulator (Panda, Mishra, Biswal, & Tripathy, 2014), etc. One of the main challenges for the BFA is to broaden its application to diverse optimization areas, especially for discrete problems.

The major purpose of this paper is to build an integrated model which can simultaneously assign/reassign workers and make production planning in multiple periods to minimize the operational costs. This paper also attempts to develop a hybrid bacteria foraging algorithm (HBFA) embedding a two-phase based heuristic (TPBH) for solving this intractable problem.

The remainder of this paper is organized as follows. The literature review related to worker assignment and production planning in CMS is presented in Section 2. The mathematical model integrating worker assignment and production planning with learning and forgetting effects is formulated in Section 3. In Section 4, the hybrid bacteria foraging algorithm embedding the TPBH is proposed. The validity of TPBH and HBFA is illustrated by a typical case. The hybrid genetic algorithm and hybrid simulated annealing for solving this problem are described in Section 5. In Section 6, numerical experiments are conducted to evaluate the proposed HBFA by comparison with the original bacteria foraging algorithm (OBFA), discrete bacteria foraging algorithm (DBFA), hybrid genetic algorithm (HGA) and hybrid simulated annealing (HSA). Finally, the paper closes with a general discussion of the proposed approach as well as a few remarks on future research directions in Section 7.

2. Literature review

In this section, we present related literature review of studies about worker assignment and production planning in designing the CMS.

2.1. Worker assignment in CMS

Many research articles are involved with worker assignment in a single-period CMS. Some researchers paid attention to models and/or model comparison. Süer, Kamat, Mese, and Huang (2013) focused on manpower allocation problem in CMS, and examined three different sharing strategies (no operator sharing allowed, sharing allowed without restrictions, sharing allowed with restrictions). They found that the models with little or no restrictions yield a higher production rate than the model with no operator sharing allowed. Süer, Arikan, and Babayigit (2009a) investigated the effects of different fuzzy operators on fuzzy bi-objective cell loading problem in labor intensive CMS. The objective is to minimize the number of tardy jobs and the total manpower needed. Süer, Arikan, and Babayigit (2008) presented four different bi-objective mathematical models to solve the cell loading problem with setup times and alternative operator configurations. Each model is to minimize two conflicted objectives including the number of tardy jobs and the total manpower needed. Süer and Dagli (2005) introduced a sub-problem of product-sequencing with the objective of minimizing the total intra-cell manpower transfers. Later, Süer, Cosner, and Patten (2009b) extended this problem by adding manpower allocation phase with the objective of minimizing the production rate. Norman, Tharmmaphornphilas, Needy, Bidanda, and Warner (2002) studied worker assignment in CMS considering both human and technical skills and their impact on system performance. The objective is to maximize system performance including the productivity, output quality and training costs. Leopairote (2003) focused on workgroup composition, worker assignment, and scheduling assuming that workers are heterogeneous in task learning–forgetting behaviors.

Some researchers are concerned with solving worker assignment problems in a single-period CMS. Egilmez, Erenay, and Süer (2014) developed a four-phased hierarchical methodology for stochastic skill-based manpower allocation problem, where operation times and customer demand are uncertain, and the objective is to maximize the CMS production rate. Liu, Wang, Leung, and Li (2016) proposed a discrete bacteria foraging algorithm for the assignment of workers and machines in the cell formation and task scheduling problem, in order to minimize the material handling costs as well as the fixed and operating costs of workers and machines. Azadeh, Sheikhalishahi, and Koushan (2013) presented an integrated fuzzy data envelopment analysis and fuzzy computer simulation approach for optimizing operator allocation in multi-product CMS with learning effects. Aalaei and Shavazipour (2013) developed data envelopment analysis method to assign workers in order to minimize backorder costs and intercellular costs. Azadeh, Nazari-Shirkouhi, Hatami-Shirkouhi, and Ansarinejad (2011b) presented a decision making approach based on Fuzzy AHP, TOPSIS and computer simulation to determine the most efficient number of operators and the efficient measurement of operator assignment in CMS. Azadeh, Kor, and Hatefi (2011a) also presented a decision making approach based on a hybrid genetic algorithm and a TOPSIS simulation to solve a similar problem.

A few research articles are involved with worker assignment in multi-period CMS. Mathur and Süer (2013) studied a CMS problem of determining weekly complete schedules with the overtime decisions on each weekend and weekday on each shift and on each cell. They compared the math model and GA approaches through experimentation and concluded that, the math model either finds optimal solution very fast, or finds a feasible solution better than the GA in relatively short period of time when the math model cannot find the optimal solution. Later, Süer and Mathur (2015) provided four extensional mathematical models for this problem, each of which reflects different overtime workforce hiring prac-