Chinese Journal of Chemical Engineering 23 (2015) 1475–1483

Contents lists available at ScienceDirect

Chinese Journal of Chemical Engineering

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

Process Systems Engineering and Process Safety

Genetic algorithm for short-term scheduling of make-and-pack batch production process

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ARTICLE INFO

Article history:
Received 19 August 2014
Received in revised form 6 March 2015
Accepted 25 April 2015
Available online 22 May 2015

Keywords:
Genetic algorithm
Ant colony optimization
Tabu search
Batch scheduling
Make-and-pack production
Forward assignment strategy

ABSTRACT

This paper considers a scheduling problem in industrial make-and-pack batch production process. This process equips with sequence-dependent changeover time, multipurpose storage units with limited capacity, storage time, batch splitting, partial equipment connectivity and transfer time. The objective is to make a production plan to satisfy all constraints while meeting demand requirement of packed products from various product families. This problem is NP-hard and the problem size is exponentially large for a realistic-sized problem. Therefore, we propose a genetic algorithm to handle this problem. Solutions to the problems are represented by chromosomes of product family sequences. These sequences are decoded to assign the resource for producing packed products according to forward assignment strategy and resource selection rules. These techniques greatly reduce unnecessary search space and improve search speed. In addition, design of experiment is carefully utilized to determine appropriate parameter settings. Ant colony optimization and Tabu search are also implemented for comparison. At the end of each heuristics, local search is applied for the packed product sequence to improve makespan. In an experimental analysis, all heuristics show the capability to solve large instances within reasonable computational time. In all problem instances, genetic algorithm averagely outperforms ant colony optimization and Tabu search with slightly longer computational time.

1. Introduction

A typical make-and-pack production problem occurs in processing plants that produces many products such as food and beverages, chemicals, and other products. A typical process starts from mixing process in a mixing tank. The mixture is transferred into multipurpose storage tanks of different capacities for a fixed period of time. Then this stored mixture is moved to packing lines. The final products in various formats are shipped to customers [1]. The objective is to determine an efficient production schedule that minimizes the makespan and satisfies customer demand. Currently, the planner of make-and-pack process finds it very difficult to determine the best short-term schedule. The planning becomes a challenging task because it involves many products and deals with many aspects such as multiple resources, partial equipment connectivity, sequence-dependent changeovers, storage time, transfer time and batch spitting. Honkomp *et al.* [1] explained a case study in details and provided data from the actual production process.

Researchers attempted to solve this problem using different techniques. For example, Fündeling and Trautmann [2] applied a priority-based heuristics by scheduling batches iteratively. The method was not effective because moderate problem could not be solved in reasonable time. Baumann and Trautmann [3] developed an efficient continuous-time precedence-based mixed integer linear program embedding with sets of symmetry-breaking constraints. The results showed that adding symmetry-breaking constraints and preprocessing step could greatly reduce CPU time and solve small and moderate instances within reasonable CPU time.

In recent years, metaheuristic methods have been applied to solve many discrete manufacturing problems. The aim of this paper is to apply a genetic algorithm (GA) to solve large make-and-pack problem. The results will be compared by solution quality and computational time with ant colony optimization (ACO) and Tabu Search (TS).

2. Literature Review

Make-and-pack problem was studied from many points of view. Baumann and Trautmann [3] summarized the literature for this particular problem. Their review focused on the model with continuous representation of time and categorized network-based models into state-task-network (STN) and resource-task-network (RTN). They concluded that none of the models could accommodate all characteristics of make-and-pack problem. The most similar model was studied by Belaid *et al.* [4] for a shampoo-production process, but their approach could not be used for make-and-pack problem because of different characteristics. Most of the techniques for STN and RTN were based on mixed integer linear programming (MILP). For example, Günther *et al.* [5] developed

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http://dx.doi.org/10.1016/j.cjche.2015.04.021
1004-9541/

an MILP model for yogurt industry. Liu *et al.* [6] developed a MILP with hybrid approach between discrete and continuous representation of time. Kopanos *et al.* [7] solved scheduling problem with family-dependent changeover using MILP technique. Velez and Maravelias [8] solved chemical production scheduling problem using multiple and nonuniform time intervals with discrete-time mixed integer programming (MIP) models. They presented two different algorithms to find effective intervals and reduced the size of the formulation. As a result, larger problem could be solved with discrete-time MIP model. Velez and Maravelias [9] improved the efficiency of solving discrete-time model using parallel computing technique and solved each subproblem as an MIP on a single core of a computer. This technique could help solve more challenging problems than the default parallel option. Karimi-Nasab and Seyedhoseini [10] solved a job shop scheduling problem by using integer linear programming formulation. The performance of cut-and-branch and branch-and-cut approaches was shown on a set of randomly-generated test data.

The make-and-pack problem is similar to batch production scheduling studied by many researchers. For example, Yu *et al.* [11] provided an overview of optimization methods for batch scheduling and constructed a benchmark problem solved with different models. They suggested that reduction of a large number of binary variables would help solve large problems. Guohui *et al.* [12] modeled this problem as a MILP model to maximize profit. A line-up competition and linear programming were used to solve two examples in literature. Their results showed better improvement compared to the earlier work. Rabie and El-Halwagi [13] optimized the schedule of batch water recycle network. New source–tank–sink presentation and iterative approach were applied to solve case study problems. Metaheuristics such as GA was also applied by various researchers. For instance, Li *et al.* [14] combined GA with MILP to solve real batch problems. Wu *et al.* [15] developed GA and modified GA approaches to find a solution for case study problems. The results showed that modified GA featuring mixed coding of two different crossover and mutation operators were more effective than GA.

This make-and-pack problem can also be categorized as multiple-product multiple-resource scheduling problem (MMSP) with some exceptions. GA was applied to solve MMPS with some successes. He and Hui [16] implemented GA with forward or backward assignment strategy to solve large MMSP in batch plant. Their results showed significant reduction in search space and enhancement of search speed. He and Hui [17] later solved MMSP using binary encoding GA. With new proposed crossover, their technique could solve large instances within reasonable time. He and Hui [18] improved the original GA in [16] by proposing a novel global search framework. A comprehensive set of position selection rules was constructed and appropriate synthesis rules were applied. Capón-García *et al.* [19] dealt with multiobjective batch process scheduling problem *via* GA and local search and focused on the trade-off between environmental impact and economical throughput.

Some researchers focused on the case study proposed by [1]. Fündeling and Trautmann [2] used a priority-based heuristics to solve make-and-pack problem by scheduling batches iteratively. They proposed 287 multi-level priority rules for computing these values. Baumann and Trautmann [3] developed an efficient continuous-time precedence-based mixed-integer linear program with symmetry-breaking constraints and special preprocessing. They applied new technique to solve a set of medium scale problems. The results were up to 12% shorter than those from the heuristics of [2]. For a large scale problem, Fündeling and Trautmann [2] reported the minimum makespan of 7946 min on the first week data from [1].

Make-and-pack problem can be also considered as a classical job shop scheduling problem (JSP), where each product type has its own route on a set of resources and machines that are fixed and known in advance. It is well known that JSP problem is NP-hard [20]. It is very difficult to obtain optimality with typical optimization technique and metaheuristics to solve JSP problem [21,22]. Hence, make-and-pack problem in this paper is also NP-hard and no solution method can ensure the global optimal for large scale problem with reasonable computational time. As it is shown in literature, GA has not been studied to solve large scale make-and-pack problem.

3. Problem Definition

For manufacturers of consumer goods industry, a typical make-and-pack process involves mixing tanks, storage tanks and packing lines. The final products are shipped to customers. High makespan means unnecessary labor cost [1]. The goal is to find the schedule that minimizes the makespan while satisfying all constraints. The details of this process are explained in Fig. 1.

Step 1: For formula A, raw materials are sent to premix tank 1 (PM1). Premix process starts at “a” and finishes at “b” and the premix batch is transferred to main mix tank from “b” to “c”. For formula B, tank PM1 needs to be cleaned first, with a change-over time from “c” to “d”. Then, premix process starts at “d” and finishes at “j” and this premix batch is transferred to main mix tank from “j” to “k”.

Step 2: For formula A, main-mix process starts production at “c” and finishes at “e” and main-mix batch is pumped out to single storage tank (ST1) from “e” to “f”. The capacity of ST1 is one batch, so one storage tank is required. For producing formula B, tank MM1 needs to be washed and there is a washout time of 47 min from “f” to “g”. Next, main-mix process starts production at “k” and finishes at “l” and main-mix batch is pumped out to two storage tanks (ST7 and ST8) from “l” to “m”. Since the capacity of both storage tanks is only 0.5 batches, two storage tanks are required. This batch splitting makes this problem more difficult to solve.

Step 3: For bulk formula A, ST1 stores mixing batch from “f” to “g” and the final product is sent to PL1. For formula B, ST7 and ST8 store mixing batch from “m” to “n” and the final product is sent to PL1 (from ST7) and PL2 (from ST8).

Step 4: For formula A, packing process starts at “g” and finishes at “h”. Task from ST8 is sent to PL1 to pack product from formula B. Packing change over time occurs at time “h–i”. PL1 then starts packing at time “n” and finish at time “o”. The process of wash out family is added from “o” to “p”.

The data for the case study are as follows.

3.1. Processing resources

There are three premix tanks and six main tanks with one-batch capacity each, six storage tanks with one-batch capacity and 74 tanks with 0.5-batch capacity, and seven packing lines supplying 0.5 batches. Furthermore, there is a restriction on the formula that premix and main mix tanks can process. Each product can be packed by a limited set of packing lines.

3.2. Demand of packed products

There are 203 packed products from 59 bulk formulas. Each formula can be packed into multiple container sizes. For product code “B5-V10-P13”, “B5-V10” represents formula name and “P13” is the packing code. Ten-week demand is given. The unit of demand is in batches and the size of batches is predetermined by processing equipment. It is assumed that due date is one week or 10080 min without a break. The requirement is to finish producing every packed product by the due date.