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Hybrid genetic algorithm and tabu search for finite capacity material requirement planning system in flexible flow shop with assembly operations

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ABSTRACT

The finite capacity material requirement planning system (FCMRP) for industrial scale flexible flow shops is known to be strongly NP-hard. Due to very long computational time, the exact method can be inappropriate for this problem. In this paper, a new hybrid improvement algorithm for the FCMRP system in a flexible flow shop with assembly operations is proposed. The proposed algorithm is a hybrid of genetic algorithm (GA) and tabu search (TS) called HGATS. There are six primary steps in HGATS. In step 1, a production schedule is generated by variable lead-time MRP (VMRP). In step 2, dispatching and random rules are applied to generate initial sequences of orders. From step 3 to step 5, the sequences of orders are iteratively improved by characteristics of TS and GA. Finally, the start times of operations are optimally determined by linear programming. The results show that HGATS outperforms GA, TS and the existing algorithm. Furthermore, HGATS requires a practical computational time when applied to real industrial cases.

1. Introduction

A main drawback of material requirement planning (MRP) is that it uses the fixed lead-time concept, which results in the production schedule with capacity problems. (Kanet & Stößlein, 2010; Lee, Trimi, Choi, & Rha, 2011; Tsai, Hwang, Chang, Lai, & Yang, 2011). One of the efficient methods to solve this problem is to integrate scheduling algorithms into MRP (Jodlbauer & Reitner, 2012; Kim, Jeong, & Park, 2008; Wang, Shen, & Hao, 2006). This integration is called a finite capacity material requirement planning system (FCMRP). The FCMRP system is one of the scheduling systems with a special characteristic that combines scheduling algorithms with MRP (Wuttipornpun & Yenradee, 2007; Wuttipornpun & Yenradee, 2014).

The FCMRP system in industrial scale production shops is normally considered NP-hard. The exact method may not be practical to be implemented since it takes a very long computational time to obtain the optimal solution. Therefore, the constructive and improvement algorithms are better approaches for the planner since they can offer a near optimal solution within a reasonable time.

This paper aims to propose a new hybrid improvement algorithm for the FCMRP system that offers a near optimal solution within a practical computational time. The proposed algorithm is a hybrid of genetic algorithm (GA) and tabu search (TS) called HGATS. The main idea of HGATS is to improve the quality of population by TS before applying GA operations in order to obtain a better solution than GA, TS and the existing constructive algorithm by Wuttipornpun and Yenradee (2014). It is intently developed for a production shop with the following characteristics:

- the production shop is a flexible flow shop with assembly operations,
- there are multi-product, multi-work centre and multi-level bill of materials (BOM),
- there are two alternative work centres for some production stages called the first and second priority work centres, and
- the first priority work centres of some operations can be the second priority work centres of other operations.

The first priority work centre is more appropriate to produce an operation than the second priority work centre in terms of cost, speed or quality. Therefore, an operation of order is intently scheduled to the first priority work centre first. If the first priority work centre is not available, the operation is then scheduled to the second one.

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This paper is further organised as follows. Section 2 deals with a literature review of the FCMRP systems conducted in the past. Section 3 presents overall characteristics of the existing algorithm and HGATS. In Section 4, the details of HGATS are discussed. Numerical examples to illustrate how HGATS works are also shown in this section. In Section 5, the details of case studies and experiments to evaluate the performance of HGATS are explained. Section 6 presents results and discussions. The performance comparison among HGATS, GA, TS and the existing algorithm based on real industrial data sets are also discussed in this section. Finally, the conclusion of this paper and recommendations for further studies are given in Section 7.

2. Literature review

This review is separated into two categories. The first category deals with the constructive algorithms developed for the FCMRP systems. Rong, Takahashi, and Morikawa (2005) and Rong, Takahashi, and Morikawa (2006) proposed MRP rescheduling heuristics for solving a multi-stage multi-machine capacitated lot-sizing problem (MSMMCLSP). This model eliminates overloads by shifting some finished goods and components backward or forward without overtime. Örnek and Cengiz (2006) proposed an algorithm for a capacitated lot sizing problem. This algorithm integrates the finite capacity scheduling into MRP with alternative routings and overtimes constraints. Wuttipornpun and Yenradee (2007) developed an algorithm that integrates the theory of constraint (TOC) with FCMRP called TOC–FCMRP. It requires higher overtimes, lower flow-time and lower tardiness than the conventional MRP system. Palaniappan and Jawahar (2009) presented a heuristic algorithm for joint optimisation of MRP and scheduling algorithms in a sequence dependent mixed model assembly line problem. Kanet and Stößlein (2010) proposed an algorithm called capacitated ERP. This algorithm integrates resource capacity constraints into the ERP planning calculations. Rossi and Pero (2011) modified the ERP planning procedures to obtain a manufacturing plan complying with resource capacity. Öztürk and Örnek (2010) and Öztürk and Örnek (2012) proposed a heuristic algorithm called Capacity Allocater and Scheduler (CAS) to remedy the drawback of MRP and provide a practical solution for industrial problems. Choi and Wang (2012) presented a decomposition-based approach (DBA) to minimise makespan in a hybrid flow shop with uncertain processing time. Tonelli, Paolucci, Anghinolfi, and Taticchi (2013) proposed two steps to obtain a feasible production schedule. The first step ensures that an intricate aggregate plan can be disaggregated to a feasible plan. The second step ensures that this detailed plan is feasible at shop floor level. Laha and Sapkal (2014) developed a heuristic algorithm to minimise total flow-time in no-wait flow shop problem. Wuttipornpun and Yenradee (2014) developed a constructive algorithm for the FCMRP system in an assembly flow shop. This algorithm tries to schedule operations of orders by various heuristics and then apply an LP model to determine optimal start times of operations in order to minimise the sum of tardiness, earliness and flow-time. Hu, Zhang, Gen, and Jo (2015) presented a new scheduling algorithm for single machine with uncertain processing time to maximise expected total weight of batches. Liao, Lee, and Lee (2015) proposed a constructive heuristic algorithm for two-stage assembly scheduling problem. This algorithm offers a near optimal solution in a very short computational time.

The second category deals with the improvement algorithms. Moon, Seo, Yun, and Gen (2006) developed a new adaptive genetic algorithm to solve a manufacturing supply chain problem considering alternative resources, sequence-dependent setup time and transportation time. Zhang and Gen (2006) proposed a multistage operation-based genetic algorithm (moGA) to minimise total makespan in a flexible manufacturing system. Costa, Cappadonna, and Fichera (2013) developed a dual encoding-based improvement algorithm for a hybrid flow shop with waiting time and machine availability constraints. Lahimer, Lopez, and Haouari (2013) proposed a new discrepancy search method based on adjacent discrepancies for minimising makespan in a multi-stage flexible flow shop problem. Bilyk, Mönch, and Almeder (2014) proposed a variable neighbourhood search (VNS) and a greedy randomised search procedure (GRSP) to solve a job shop with parallel machines. Chou, Chien, and Gen (2014) proposed a hybrid multiobjective approach based on genetic algorithm and variable neighbourhood descent algorithm to solve a flexible job shop scheduling problem. M'Hallah (2014) proposed an approximate solution using variable neighbourhood search and mixed integer programming to minimise total earliness and tardiness for permutation flow shop. Zhang, Gen, and Jo (2014) developed a hybrid sampling strategy-based multiobjective evolutionary algorithm for process planning and scheduling. Costa (2015) developed a hybrid of genetic algorithm with two-stage encoding and local search for parallel machines problem. Dong, Nowak, Chen, and Lin (2015) developed a self-adaptive perturbation and multi-neighbourhood structure for iterated local search to minimise total flow time in permutation flow shop. Rahman, Sarker, and Essam (2015) presented a model of make-to-stock permutation flow shop considering a length of production cycle, batch size and order of products in each cycle simultaneously. Wang, Choi, and Lu (2015) proposed a hybrid estimation of distribution algorithm and genetic algorithm for a permutation flow shop with uncertain processing time. The result shows that the proposed algorithm outperforms the others in both solution quality and computational time.

From the review, it can be seen that many constructive and improvement algorithms are developed for various FCMRP systems. An advantage of the constructive algorithm is that it offers a solution within a short computational time. The reason for this is that it searches within a specific solution space. However, the solution quality obtained from the constructive algorithm depends on the quality of its initial solution, and normally this solution can be further improved especially in complex industrial problems. Unlike the constructive algorithm, the improvement algorithm normally takes a longer computational time since it searches in many solution spaces for seeking a better solution. To the best of author's knowledge about the FCMRP system, there are only a few papers that try to solve this problem by hybrid improvement algorithms. A reason for this is that it is difficult to find a proper hybrid algorithm that significantly outperforms an individual algorithm. This paper aims to contribute the research in this area by proposing a new hybrid improvement algorithm that offers a better solution than an individual improvement algorithm and the existing constructive algorithm by Wuttipornpun and Yenradee (2014).

3. Characteristics of the existing algorithm and HGATS

This section presents a discussion about overall characteristics of the existing algorithm and HGATS. All procedures of both algorithms are shown in Figs. 1 and 2, while the overall characteristics of these algorithms are summarised in Table 1.

There are two similarities for both algorithms, which are characteristics 1 and 4. The first similarity is that they apply variable lead-time MRP (VMRP) to generate a production schedule. An advantage of the VMRP system is that the production schedule generated from this system is more realistic than the conventional MRP system. The second similarity is that they apply the forward