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A hybrid Lagrangian-simulated annealing-based heuristic for the parallel-machine capacitated lot-sizing and scheduling problem with sequence-dependent setup times

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ABSTRACT

This paper examines the parallel-machine capacitated lot-sizing and scheduling problem with sequence-dependent setup times, time windows, machine eligibility and preference constraints. Such problems are quite common in the semiconductor manufacturing industry. In particular, this paper pays special attention to the chipset production in the semiconductor Assembly and Test Manufacturing (ATM) factory and constructs a Mixed Integer Programming (MIP) model for the problem. The primal problem is decomposed into a lot-sizing subproblem and a set of single-machine scheduling subproblems by Lagrangian decomposition. A Lagrangian-based heuristic algorithm, which incorporates the simulated annealing algorithm aimed at searching for a better solution during the feasibility construction stage, is proposed. Computational experiments show that the proposed hybrid algorithm outperforms other heuristic algorithms and meets the practical requirement for the tested ATM factory.

1. Introduction

The Capacitated Lot-sizing and Scheduling Problem (CLSP) considered in this paper involves multiple single-level items to be processed on unrelated parallel machines over several time periods. Single-level items mean that no item among them is a predecessor or a successor of another. The objective is to determine the production quantities, item assignment, and sequencing on each machine for each time period without violating the machine capacity limits to minimize the sum of inventory holding cost, backlog cost, setup cost and machine preference cost, subject to sequence-dependent setup times, time windows, machine eligibility and preference constraints. This multi-item CLSP is frequently encountered in manufacturing industries especially in the semiconductor manufacturing industry. In particular, this paper is based on the chipset production in the semiconductor Assembly and Test Manufacturing (ATM) factory. A typical semiconductor ATM production line includes: wafer reflow, mount, saw, chip attach module, deflux, epoxy cure, burn in, test, ball attach, inspection and packing. The ball-attach machines which attach balls to the substrate of a chipset are usually regarded as the bottleneck station of the ATM production line due to their high machine utilization and long sequence-dependent setup times. Solving this problem is difficult due to the existence of multiple complicated constraints. Currently, it takes schedulers several hours to generate a solution based on their experiences by trial and error. However, the solution often turns out to be unsatisfactory in terms of both computational time and solution quality. Therefore, seeking an effective and efficient solution approach is of great significance.

The ball attach station typically involves the following four constraints: firstly, the machine setup time between different items is sequence-dependent varying from 0.5 to 6 h which has a significant impact on capacity usage. Secondly, there are time window restrictions on the production starting time and due time for each item, which means the item cannot be processed before its release time, and the delivery beyond the due time may incur backlog penalty costs. On the one hand, it is obvious that the items may not be ready for the operation at the bottleneck station before the completion of its upstream stations, and on the other hand, a due time is often set for each item at the bottleneck station in order to meet the time requirements of downstream stations. Thirdly, not all parallel machines in the station are eligible for every incoming item since new items and new machines are continuously introduced. Old machines that are still working in the same station may become obsolete for processing new items. Therefore, each item can only be processed by a certain subset of eligible machines. Fourthly, in practice it is often required to place

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the items on their respective preferable machines for the consideration of item quality and machine reliability.

Although a lot of research has been done on the extensions of CLSP, to the best of our knowledge, the CLSP with the multiple constraints presented in this paper is scant in the literature. This problem with these constraints also exists extensively in industrial fields, such as the metal foundry [1], iron and steel complex [2], and chemical industry [3]. Furthermore, scale of production is expected to expand in the future with the development of the world economies. All these factors motivate this paper to propose an appropriate model and to design an effective algorithm to solve the considered problem.

The main contributions of this paper are to:

1. Proposes a mathematical model considering several practical constraints simultaneously, i.e., sequence-dependent setup times, time windows, machine eligibility, and machine preference.
2. Design an effective algorithm to solve the problem. Although such a problem can be solved by Cplex in some scenarios under small size context, it is not possible to obtain desired solution by Cplex or existing algorithms when the problem size expands or when the problem is small but with high levels of density of the machine–item qualification matrix and high demand probability.

The remainder of this paper is organized as follows: Section 2 briefly reviews the existing literature. The MIP model is formulated considering the multiple constraints in Section 3. By integrating the Lagrangian relaxation and the simulated annealing algorithm, a Hybrid Lagrangian-Simulated Annealing-based heuristic algorithm (HLSA) is proposed in Section 4. The experimental design and numerical experiments are presented in Section 5. Finally Section 6 concludes the paper and points some directions for future research.

2. Literature review

Florian et al.[4] showed that the single item CLSP problem is NP-hard. Therefore, our multi-item CLSP problem with multiple constraints is an NP-hard as well. The exact solution approaches cannot solve large-size problems within a reasonable amount of time. In the rest of this section, we will give a literature review from the perspectives of problem characteristics and heuristic algorithms. To make it easier to capture the features of the problems studied in the existing literature and this paper, we summarize them in Table 1.

Most existing research assumed no setup time or only considered the sequence-independent setup times in the CLSP problems. Karimi et al. [5], Özdamar et al. [6], and Hindi et al. [7] considered the single-machine lot-sizing problem with sequence-independent setup times. Özdamar and Barbarosoğlu [8], Stadtler [9], Sahling et al. [10] and Wu et al. [11] studied the multi-level CLSP problem with sequence-independent setup times. They proposed different heuristic algorithms to solve such a problem. Toledo and Armentano [12] developed a heuristic based on the Lagrangian relaxation of the capacity constraints and sub-gradient optimization for solving the problem with multiple items on unrelated parallel machines and sequence-independent setup times. González-Ramírez et al. [13], Degraeve and Jans [14], and Wu et al. [15] addressed how the multi-item capacitated lot-sizing problems with sequence-independent setups were solved by the Dantzig–Wolfe decomposition with the capacity constraints as the linking constraints.

Our problem is an extension of the capacitated lot-sizing problem with sequence-dependent setup costs (CLSD) proposed by Haase [16] whose research addressed a single-machine case without considering the setup times. For a single-machine problem with sequence-dependent setup times, Kovács et al. [17] transformed it into a Travelling Salesman Problem (TSP) and determined the optimal sequence by dynamic programming. Beraldi et al. [18] developed a fix-and-relax heuristic for the single machine and identical parallel-machine CLSP with sequence-dependent setup times. Lang and Shen [19] developed MIP-based fix-and-relax and fix-and-optimize heuristics for the single machine CLSP problem with sequence-dependent setup times and item substitution options. James and Almada-Lobo [20] proposed iterative MIP-based neighbourhood search heuristics for the single

Table 1
Literature summary.

Problem type	Reference	ME	TW	MP	Capaci-tated	Setup time		Setup cost		Machine			Item		
						SID	SD	SIC	SC	Single	IPM	URM	Single	sin-lev	mul-lev
Lot-sizing	[5,6]				√	√		√		√				√	
	[12]				√	√		√				√		√	
	[13–15]				√	√				√				√	
	[27]									√			√		
	[28]					√						√			√
	[29]				√	√		√				√			
	[30]		√		√										
	[32]		√					√						√	
CLSP	[7]				√	√				√				√	
	[8–11]				√	√		√				√			√
	[17,19]				√		√		√	√				√	
	[18]								√	√	√			√	
	[20]		√				√		√	√			√		
	[31]		√		√	√				√				√	
	[35,36]				√		√			√				√	
CLSD	[16]				√				√	√				√	
CLSPL	[22]				√	√				√				√	
	[23]				√			√		√			√		
	[24]				√		√			√					
	[34]				√	√		√			√			√	
	This	√	√	√	√		√					√		√	

ME = machine eligibility, TW = time window, MP = machine prefer, SID = sequence-independent setup time, SD = sequence-dependent setup time, SIC = sequence-independent setup cost, SC = sequence-dependent setup cost, IPM = identical parallel machine, URM = unrelated parallel machine, sin-lev = single level, mul-lev = multi-level.