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Earliness–tardiness minimization on scheduling a batch processing machine with non-identical job sizes ☆

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ABSTRACT

This paper considers the scheduling problem of minimizing earliness–tardiness (E/T) on a single batch processing machine with a common due date. The problem is extended to the environment of non-identical job sizes. First, a mathematical model is formulated, which is tested effectively under IBM ILOG CPLEX using the constraint programming solver. Then several optimal properties are given to schedule batches effectively, and by introducing the concept of ARB (Attribute Ratio of Batch), it is proven that the ARB of each batch should be made as small as possible in order to minimize the objective, designed as the heuristic information for assigning jobs into batches. Based on these properties, a heuristic algorithm MARB (Minimum Attribute Ratio of Batch) for batch forming is proposed, and a hybrid genetic algorithm is developed for the problem under study by combining GA (genetic algorithm) with MARB. Experimental results demonstrate that the proposed algorithm outperforms other algorithms in the literature, both for small and large problem instances.

1. Introduction

A batch processing machine that processes a group of jobs simultaneously is encountered in many industries, such as semiconductor manufacturing and metal heat treatment. For example, in semiconductor manufacturing, a burn-in oven is regarded as a batch processing machine which can process a number of IC chips simultaneously. Burn-in process is often a bottleneck step in the back-end process of semiconductor manufacturing, as its processing time is significantly longer than that of other steps and it is near the end of the production process. So scheduling on burn-in ovens will impact both on-time customer delivery and cost performance. Motivated by this, there have been numerous studies of scheduling on batch processing machines. Mönch, Fowler, Dauzere-Peres, Mason, and Rose (2011, 2013) presented a review of scheduling semiconductor manufacturing operations, and most of related studies have focused on such regular measures as makespan, total completion time, and maximum lateness. However, the emphasis has changed with the current interest in Just-In-Time (JIT) production, which requires jobs to be completed exactly on time. Jobs completed before the due date may result in earliness, which may result in a holding cost, while jobs completed after the due date cause tardiness, which may lead to customer dissatisfaction. JIT asserts that earliness/tardiness should be eliminated in order to control costs of the production process.

The objective of this paper is to minimize the sum of the absolute deviations of completion times from the due date of all jobs (E/T), which directly reflect the cost of both inventory (earliness) and customer dissatisfaction (tardiness). That all jobs have a non-restrictive common due date is assumed in this paper. The situation of common due date occurs in many production process, such as base wafers in the front-end of burn-in ovens. Base wafers are preprocessed wafers and are then held on stock for further processing based on specific customer requests. In this situation, the due dates of almost all final chips from the base wafers are the same in the back-end. The assumption of nonrestrictive due date was introduced by Kanet (1981) and Hall and Posner (1991) that all jobs have due date $d > C$ where C is the makespan of the given job set, which ensures that the scheduling procedure does not require jobs to be processed at time zero and due date would not act as a major constraint on the schedule decision.

In this paper, we consider the E/T minimization problem with the environments of non-identical job sizes, which makes the

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problem more practical. In semiconductor manufacturing, a job corresponds to numerous integrated circuits. Jobs need to be loaded on to boards before they are processed and the boards are then loaded into a burn-in oven (Uzsoy, 1994). The size of a job is defined by the number of boards it requires and a number of jobs are batched to be processed in the same oven. Jobs differ not only in processing time, but also in size in practical production environments. To solve this problem, we first characterize several properties about an optimal solution, which indicate us how to schedule the formed batches effectively. Then by introducing the concept of ARB (Attribute Ratio of Batch), a heuristic algorithm MARB (Minimum Attribute Ratio of Batch) is proposed, which assumes that the ARB of each batch should be as small as possible. Combined with MARB, a hybrid genetic algorithm is developed for solving the problem under study. Experimental results show that the proposed algorithm achieves better performance than existing algorithms.

The remainder of this paper is organized as follows: Section 2 gives a related literature review; Section 3 describes the proposed problem; several optimal dominant properties are proven in Section 4; new algorithms are proposed in Section 5; and Section 6 illustrates the computational experiments of the algorithms. A summary and discussion of future research directions concludes the paper in the last section.

2. Related work

The problem of scheduling on batch processing machines have received tremendous attention since it was first proposed by Ikura and Gimple (1986). Lee, Uzsoy, and Martinvega (1992) proposed efficient algorithms for minimizing a number of different objectives, such as the number of tardy jobs, maximum tardiness and makespan. Chandru, Lee, and Uzsoy (1993) developed a branch-and-bound algorithm and several heuristic algorithms for minimizing total completion time on a single burn-in oven. Li and Lee (1997) investigated the batch scheduling problems of minimizing the maximum tardiness and minimizing the number of tardy jobs and proved both are strongly NP-hard.

All of the above studies examined problems with unit job size. Uzsoy (1994) was the first to consider the importance of scheduling on burn-in ovens with non-identical job sizes and proposed several heuristics for problems of minimizing makespan and total completion time. After that, Sung and Choung (2000) proposed a branch-and-bound algorithm and several heuristics for makespan minimization on a single burn-in oven. Damodaran, Manjeshwar, and Srihari (2006) examined the same problem using a genetic algorithm (GA), and the results indicated GA outperformed previous algorithms. Chen, Du, and Huang (2011) provided a novel insight into scheduling on a batch processing machine from a clustering perspective and developed a clustering algorithm. Xu, Chen, and Li (2012) investigated the batch scheduling problem with dynamic job arrivals, using an ant colony optimization (ACO) metaheuristic to minimize the makespan.

Most of the studies mentioned above concentrated on the batch scheduling problem with such regular measures as makespan, total completion time, and maximum lateness. Kanet (1981) was the first to introduce the problem of E/T minimization on a single discrete processing machine which processes one job at a time. The unrestrictive common due date was assumed, which had no influence on the optimal schedule. Kanet proposed an optimal polynomial time algorithm and proved the optimal schedule is V-shaped. Hall and Posner (1991) proved that the weighted E/T problem is NP-complete and developed an optimal pseudo-polynomial time algorithm. Feldmann and Biskup (2003) applied several metaheuristics, including evolutionary search (ES), simulated annealing (SA), and threshold accepting (TA) for the E/T scheduling problem with earliness/tardiness penalties against the restrictive common due date. Ying (2008) investigated the same problem as Feldmann and Biskup (2003), and presented an effective recovering beam search (RBS) algorithm.

With more interest on batch scheduling, Qi and Tu (1999) studied the E/T minimization problem on single batch processor with same processing time and distinct due date of jobs, and proposed a dynamic programming algorithm. Sung, Choung, and Fowler (2002) proposed a property-based heuristic (PBH) algorithm to minimize E/T on a single burn-in oven with unit job size and a common due date. Choung and Mönch (2003) suggested a hybrid genetic algorithm for the same problem in Sung et al. (2002). Experiment results showed the GABASH (Genetic Algorithm Based Batch Assignment and Sequencing Heuristic) algorithm outperformed PBH. Mönch, Unbehaun, and Choung (2006) extended the E/T minimization problem with a common due date and identical job size to the constraint of maximum allowable tardiness. Mönch and Unbehaun (2007) suggested three different decomposition heuristics for the E/T scheduling problem on parallel burn-in ovens. Zhao, Hu, and Li (2006) gave a polynomial algorithm for a common due window scheduling problem with batching on a single machine to minimize total penalty of E/T. Pan and Zhou (2008) proposed a weighted cost rate heuristic (WCRH) algorithm for minimizing E/T with delivery restriction and distinct due dates. Yin, Cheng, Xu, and Wu (2012) considered a problem with a common due date in a batch delivery system. The costs of earliness, tardiness, inventory, and batch delivery were involved, and the proposed solution tried to find a trade-off for minimizing the total costs. This paper extends the problem from Sung et al. (2002) to the case of non-identical job sizes constraint.

3. Problem definition and modeling

This paper considers a scheduling problem with n jobs and a single batch processing machine. The following assumptions are made for our problem.

(1) There are n jobs to be processed on a single batch processing machine. Each job has a corresponding processing time p_j and size s_j. All jobs have the nonrestrictive common due date d, which is set greater than or equal to the makespan of the given job set.
(2) The machine has a fixed capacity B and the capacity of the batch processing machine is measured in pieces. The total sizes of all the jobs in a batch cannot exceed the capacity of the machine. The processing time of a batch is given by the longest processing time of all the jobs in this batch.
(3) All the jobs are available at time zero, and an idle time before processing of a schedule is allowed.
(4) Once processing of a batch is initiated, it cannot be interrupted; no jobs can be removed from or introduced into the batch until processing is completed.

In order to explain our mathematical model, other notations are defined as follows:

b_k	the kth batch
n_k	total number of jobs in the kth batch
T_k	processing time of the kth batch
C_k	completion time of the kth batch
$f(S)$	E/T under a schedule S
α	job set of earlier jobs completed before or on due date
β	job set of tardy jobs completed after due date
N_α	total number of jobs in α
N_β	total number of jobs in β