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Integrated decision making for parts ordering and scheduling of jobs on two-stage assembly problem in three level supply chain

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ABSTRACT

This paper presents an integrated model for two-stage assembly scheduling problem with ordering the required parts in three-level supply chain including parts' suppliers, components' manufacturers and an assembler. It considers the quantity and date of parts' order as decision variables to make the problem seem more realistic. A mixed-integer linear programming model is proposed to minimize sum of the total weighted completion time, parts ordering and holding cost.

A genetic algorithm (GA) based heuristic is proposed to solve the problem efficiently since it is NP-hard, whose solutions are compared with those of CPLEX. Computational experiments were conducted through a diverse range of problem instances indicating that the GA performs much better than CPLEX regarding the average percentage of improvement, ranging from 2.96% to 37.70%, and CPU time. The existing study has considered the effect of machine specific and shared parts aligned with integrated decisions. Results indicate that, adding more of both specific and shared parts and increasing the number of jobs lead to dramatic decrease in the performance of CPLEX in comparison with GA. As the results reveal, the integrated model provides enhancements for the supply chain performance up to 8.16%. Furthermore, the permutation and non-permutation types of the problem are analyzed. The obtained Results show that permutation schedules are not sufficient to solve two-stage assembly scheduling problem within inventory constraints.

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1. Introduction

In the recent competitive environment, cost reduction plays a crucial role in supply chain success. Cost savings can be yielded through various methods one of which is to integrate decisions at different levels. Effective supply- chain design comprises several complex inter-related problems, such as routing, inventory management and scheduling. These problems are typically difficult to solve even though one ignores the interrelationship between decision-making levels and facilities. For example, many deterministic scheduling problems occurring within a single facility are known to be NP-hard [1]. For real problems, the complexity of the problem is increased by considering different decision-making levels simultaneously. The current paper focuses on integrating a three-level supply chain model including parts suppliers, components manufacturers and an assembler to minimize the costs associated with ordering, inventory and scheduling.

The problem can be defined as follows: In an assembly flow shop scheduling problem, there are n jobs each of which has $m+1$ operations and there are $m+1$ machines to perform each operation. Each machine can process only one job at a time. For each job, the first m operations are conducted at the first stage in parallel and a final operation in the second stage. Each of m operations at the first stage is performed by a different machine and the last operation at the second stage may start only after completing all m operations at the first stage [2].

The problem of two-stage assembly in a flow shop scheduling looks authentic and practical that can be applied for many real-life aspects. We can consider the production of an item with different components in a manufacturing firm as an assembly flow shop scheduling problem [3]. By this problem each component requires one or more parts. Accordingly, the parts inventory plays a decisive role in the two-stage assembly scheduling problem. Previous researches, except in rare cases, of this issue have been mostly ignored [4]. While making decisions, the ordering quantity and ordering point (date) of each part should be included in the problem as significance. Recently, a few researches consider parts inventory information such as arrival time and quantity of parts as parame-

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ters and constraints for machines scheduling problems which can be observed [4–6].

In the existing study, the problem of a three-stage assembly flow shop aligned with the inventory constraints and ordering parts in the first stage has been considered. The parts ordering quantity and date of ordering parts have been assumed as decision variables. In fact, two different levels of decision-making including determination of quantity and date of ordering parts and jobs scheduling on m + 1 machine are intended simultaneously. Component processing starts when all the required parts of a component are available. Likewise, at the third stage, the assembly operation starts after the completion of all m operations at the second stage. The model considered in this paper is an extension of a model proposed by Terekhov et al. [4]. According to the results they pinpointed, when there are no shared parts among manufacturers, the MIP model based on time-index formulation will be the best model for problems with short processing time.

Consequently, we proposed a Mixed Integer Linear Program (MILP) model based on time-indexed variables for the two-stage assembly scheduling with ordering the required parts in the three-level supply chain. In the proposed problem, determination of quantity and date of parts ordering are decision variables and the goal is to find an optimal sequence of processing components in each machine and the date and quantity of orders for each part to minimize the sum of the total of weighted completion time of jobs and inventory costs (sum of ordering and holding costs) of parts.

This paper has been constituted as follows: Section 2 represents a literature review of the related studies. Section 3 presents a description of the problem and a MILP model that has been developed for the problem. The new projected GA has been explained in details through Section 4 and the description of GA for permutation scheduling problem is given in Section 5. Computational experiments are also provided in Section 6. The comparison between permutation and non-permutation problem, the evaluation of the effect of machine-specific and shared parts and comparison between integration and non-integration model have been studied in Section 7. Finally, conclusions and future works have been made in Section 8.

2. Literature review

The two-stage assembly scheduling problem has many applications in industry. Potts et al. [7] described an application in the production of personal computers, while Lee, Cheng et al. [8] described another application in a fire engine assembly plant. Another example of the problem presented by Al-Anzi and Allahverdi [9] in the area of queries scheduling on distributed database systems. In fact, many real life problems can be modeled as a two-stage assembly flow shop scheduling problem.

The two-stage assembly scheduling problem is a generalization of the two-machine flow shop problem. Lee, Cheng et al. [8] and Potts et al. [7] studied the two-stage assembly flow shop problem with the objective of minimizing the makespan and both proved that the problem with this objective function is NP-hard in the strong ksense even when number of the machines at the first stage is equal to two. Lee, Cheng et al. [8] presented a branch and bound algorithm to solve the problem. They also proposed three heuristics and analyzed their error bounds. Potts et al. [7] showed that permutation schedules are dominant and proposed a heuristic algorithm with a worst case ratio bound of 2–1/m. Tozkapan et al. [10] considered this problem with the total weighted flow time performance measure. They developed a lower bound, which seemed to work well for reasonable sized problems. Also, they proposed a heuristic for large sized problems. Allahverdi and Al-Anzi [9] considered the problem presented by Tozkapan et al. [10] with respect to total completion time criterion. They developed a simulated annealing (SA), a tabu search (TS) and a hybrid TS algorithm for general cases. The computational analysis showed that the proposed hybrid Tabu search heuristic improves the error rate by about 60 and 90 percent over Tabu search and simulated annealing heuristics, respectively, where the CPU time of all the three heuristics is almost the same. Sung and Kim [11] considered a two-stage multiple-machine assembly scheduling problem for minimizing the sum of completion times. They developed a branch-and-bound algorithm and an efficient simple heuristic algorithm. In addition, Al-Anzi and Allahverdi [12] minimized the bi-criteria of makespan and maximum tardiness and presented three heuristics based on TS, particle swarm optimization (PSO) and self-adaptive differential evolution (SDE) to solve the problem. The computational experiment revealed that both PSO and SDE are much superior to Tabu. Moreover, it is statistically shown that PSO performs better than SDE. The computation times of both PSO and SDE are close to each other and they are less than 40 and 45 s, respectively, for the largest size problem considered. Allahverdi and Al-Anzi [13] addressed the problem with m machines at the first stage and setup times are assumed as separate from processing times. They minimized the total completion time and developed a SDE, a Hybrid tabu search (Ntabu) and a new self-adaptive differential evolution (NSDE) to solve the problem. The result showed that the Ntabu is known to be the best for the case when setup times are zero. It is shown that the newly proposed NSDE performs much better than SDE and Ntabu (even for the case when setup times are zero). Therefore, NSDE is also the best heuristic for the problem where setup times are ignored. Tian et al. [14] proposed discrete particle swarm optimization algorithm (DPSO) to solve the problem with respect to bicriteria of makespan and mean completion time. The results showed that DPSO is an effective and efficient for assembly scheduling problem. Allahverdi and Aydilek [15] considered the problem with respect to minimizing total tardiness. They assumed setup times as zero and proposed an insertion algorithm, a genetic algorithm; two versions of SA algorithm and two versions of cloud theory-based SA. Computational analysis indicated that one of the versions of the SA combined with the PIA performs better than the rest of the algorithms. Allahverdi and Aydilek [3] considered the problem presented by Allahverdi and Aydilek [15] with separate setup times. They proposed two new algorithms and adapted four existing algorithms. The algorithms are different versions of SA, GA, and insertion algorithms. Extensive computational showed the error of the best algorithm is less than those of the other algorithms by 54%–98%. Mozdgir et al. [16] extended the problem by considering a number of non-identical assembly machines in the second stage to minimize a weighted sum of makespan and mean completion time. They provided a MILP model and proposed a hybrid variable neighborhood search heuristic to solve this problem. Computational experiments revealed that the hybrid VNS heuristic perform much better than GAMS with respect to the percentage errors and run times. Navaei et al. [17] also studied the problem with multiple non-identical assembly machines. They considered minimizing the makespan and developed a MILP formulation for this problem. They also presented hybrid-SA algorithm to solve this problem. The computational results showed the effectiveness of the proposed hybrid-SA algorithm in terms of percentage errors and run times. Komaki and Keyvanfar [18] addressed the two-stage assembly flow shop scheduling problem with release date of jobs and identical parallel machines in the second stage. They aimed to minimize the makespan and presented a novel meta-heuristic algorithm called Grey Wolf Optimizer (GWO) to solve the problem. Finally, the experiments showed that the GWO outperforms the other employed well-known meta-heuristic algorithms.

Traditional two-stage assembly scheduling problem has been extended in various forms. Koulamas and Kyparisis [19] general-

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