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Editorial

Special Issue on Algorithms for Scheduling Problems

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Abstract: This special issue of *Algorithms* is devoted to the development of scheduling algorithms based on innovative approaches for solving hard scheduling problems either exactly or approximately. Submissions were welcome both for traditional scheduling problems as well as for new practical applications. The main topics include sequencing and scheduling with additional constraints (setup times or costs, precedence constraints, resource constraints, and batch production environment) and production planning and scheduling problems arising in real-world applications.

Keywords: scheduling; single-stage systems; multi-stage systems; single-criteria objective; multi-criteria objective; production planning

1. Introduction

Optimal scheduling (and sequencing) is an important area of operations research since it has both theoretical and practical aspects. It is clear that efficient (or better polynomial) algorithms are most desirable for a practical application since most real-world scheduling problems have large sizes. Due to this, practitioners often prefer to use rather simple scheduling algorithms which provide, however, schedules that may be far from the optimal ones with respect to their quality.

This special issue contains both theoretical and practical works in the field of scheduling algorithms. We hope that practical schedulers will find some interesting theoretical ideas in this special issue, while researchers will find new practical directions for implementing their scheduling algorithms.

2. Special Issue

In response to the call for papers, we selected eleven submissions for this special issue, all of which are of high quality, reflecting the stable and growing interest in the area of effective and efficient algorithms to solve problems for real-world production planning and scheduling. All submissions have been reviewed by at least three experts in the operations research area. Next, we survey all published papers in increasing order of their publication dates for this special issue.

The paper [1] was the first one accepted for this special issue, where the authors wrote that, to improve energy efficiency and maintain the stability of the power grid, time-of-use (TOU) electricity tariffs have been widely used around the world, which bring both opportunities and challenges to energy-efficient scheduling problems. Although methods based on discrete-time or continuous-time models have been suggested for addressing these problems, they are deficient in solution quality or time complexity, especially when dealing with large-size instances. For such problems, a new greedy insertion heuristic algorithm with a multi-stage filtering mechanism including coarse granularity

and fine granularity filtering is developed in this paper. To show the effectiveness of the proposed algorithm, a real case study is provided and detailed computational results are given.

The paper [2] is devoted to a graph model of hierarchical supply chains. The goal is to measure the complexity of the links between different components of the chain, e.g., between the principal equipment manufacturer and its suppliers. The information entropy is used as a measure of knowledge about the complexity of shortages and pitfalls in relationship to the supply chain components under uncertainty. The concept of conditional entropy is introduced as a generalization of the conventional entropy. An entropy-based algorithm is developed providing an efficient assessment of the supply chain complexity as a function of the supply chain size.

In the paper [3], the maximization of the number of just-in-time jobs in a permutation flow shop scheduling problem is considered. A mixed integer linear programming model to represent the problem as well as solution approaches based on enumerative and constructive heuristics are proposed and computationally implemented. The 10 constructive heuristics proposed produce good-quality results, especially for large-scale instances in reasonable time. The two best heuristics obtain near-optimal solutions, and they are better than adaptations of the classic NEH heuristic.

The paper [4] is devoted to a formalization of the resource-constrained project scheduling problem (RCPSP) in terms of combinatorial optimization theory. The transformation of the original RCPSP into a combinatorial setting is based on interpreting each operation as an atomic entity that has a defined duration and has to reside on the continuous time axis meeting additional restrictions. The simplest case of continuous-time scheduling assumes a one-to-one correspondence between the resources and operations and corresponds to a linear programming problem setting. However, real scheduling problems include many-to-one relations that lead to an additional combinatorial component in the formulation of the RCPSP due to the competition of the operations. The authors investigate how to apply several typical algorithms to solve the resulting combinatorial optimization problem: an enumerative algorithm including a branch-and-bound method, a gradient algorithm, or a random search technique.

The paper [5] considers a number of markets, geographically separated, with different demand characteristics for different products that share a common component. This common component can either be manufactured locally in each of the markets or transported between the markets to fulfill the demand. However, final assemblies are localized to the respective markets. The decision-making challenge is whether to manufacture the common component centrally or locally. To formulate this problem, a newsvendor modeling-based approach is considered. The developed model is solved using a Frank–Wolfe linearization technique along with Benders' decomposition method.

The paper [6] is devoted to the effectiveness in managing disturbances and disruptions in railway traffic networks, when they inevitably do occur. The authors propose a heuristic approach for solving the real-time train traffic re-scheduling problem. This problem is interpreted as a blocking job-shop scheduling problem, and a hybridization of the mixed graph and alternative graph is used for modeling the infrastructure and traffic dynamics on a mesoscopic level. A heuristic algorithm is developed and applied to resolve the conflicts by re-timing, re-ordering, and locally re-routing the trains. A part of the Southern Swedish railway network from the center of Karlskrona to Malmö city is considered for an experimental performance assessment of the approach. A comparison with the corresponding mixed-integer program formulation, solved by the commercial state-of-the-art solver Gurobi, is also made to assess the optimality of the generated solutions.

In the paper [7], it is written that the current literature presents optimal control computational algorithms with regard to state, control, and conjunctive variable spaces. The authors of this paper first analyze the advantages and limitations of different optimal control computational methods and algorithms which can be used for short-term scheduling. Second, they develop an optimal control computational algorithm that allows the solution of short-term scheduling in an optimal manner. Moreover, a qualitative and quantitative analysis of the scheduling problem arising in the manufacturing system is presented.

The paper [8] is devoted to a stability approach to scheduling problems with uncertain parameters. The stability approach combines a stability analysis of the optimal schedules with respect to possible variations of the job processing times, a multi-stage decision framework, and the solution concept of a minimal dominant set of schedules, which optimally covers all possible scenarios, i.e., for any fixed scenario, this minimal dominant set contains at least one optimal schedule. In contrast to fuzzy, stochastic, and robust approaches, the aim of the stability approach is to construct a schedule, which remains optimal for the most possible scenarios. If there exists a schedule dominating the other ones for all possible scenarios, then this schedule remains optimal for each scenario, which may be realized. This may be possible, if the level of uncertainty is not high. Otherwise, a decision-maker must look for a schedule, which provides optimal, or close to optimal, objective function values for the most possible scenarios among other schedules. To this end, the desired schedule must dominate a larger number of the schedules. This may be possible if the schedule has the largest optimality (stability) box. The authors address a single machine scheduling problem with uncertain durations of the given jobs. The objective function is the minimization of the sum of the job completion times. The stability approach is applied to the considered uncertain scheduling problem using the relative perimeter of the optimality box as a stability measure of the optimal job permutation. The properties of the optimality box are investigated and used to develop algorithms for constructing job permutations that have the largest relative perimeters of the optimality box.

The paper [9] addresses a scheduling problem in an actual environment of the tortilla industry. A tortilla is a Mexican flat round bread made of maize or wheat often served with a filling or topping. It is the most consumed alimentation product in Mexico, so efficient algorithms for their production are of great importance. Since the underlying hybrid flow-shop problem is NP-hard, the authors focus on suboptimal scheduling solutions. They concentrate on a complex multi-stage, multi-product, multi-machine, and batch production environment considering completion time and energy consumption optimization criteria. The proposed bi-objective algorithm is based on the Non-Dominated Sorting Genetic Algorithm II (NSGA-II). To tune it up, the authors apply a statistical analysis of multi-factorial variance. A branch-and-bound algorithm is used to evaluate the heuristic algorithm. To demonstrate the practical relevance of the results, the authors examined their solution on real data.

The paper [10] deals with an image processing work-flow scheduling problem on a multi-core digital signal processor cluster. It presents an experimental study of scheduling strategies including task labeling, prioritization, and resource selection. The authors apply the above strategies as executing the Ligo and Montage application. A joint analysis of three conflicting goals based on the performance degradation provides an effective guideline for choosing a better strategy. A case study is discussed. The experimental results demonstrate that a pessimistic scheduling approach works better than an optimistic one and leads to the best optimization criteria trade-offs. The pessimistic heterogeneous earliest finish time (PHEFT) scheduling algorithm performs well in different scenarios with a variety of workloads and cluster configurations. The developed PHEFT strategy also has a lower time complexity in comparison with earlier versions known as HEFT (heterogeneous earliest finish time first).

The last paper accepted for this special issue is [11], which addresses a scheduling problem, where jobs with given release times and due dates have to be processed on a single machine. The primary criterion of minimizing the maximum lateness of the given jobs makes this problem strongly NP-hard. The author proposes a general algorithmic scheme to minimize the maximum lateness of the given jobs with the secondary criterion of minimizing the maximum completion time of the given jobs. The problem of finding a Pareto optimal set of solutions with the above two criteria is strongly NP-hard as well. The author states properties of the dominance relation along with conditions when a Pareto optimal set of solutions can be found in polynomial time. The proven properties of the dominance relation and the proposed general algorithmic scheme provide a theoretical background for constructing an implicit enumeration algorithm that needs an exponential running time and a

polynomial approximation algorithm. The latter allows for the generation of a Pareto sub-optimal frontier with a fair balance between the above two criteria.

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