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A review of literature: Exploring synergies between scheduling problems and cutting stock challenges in industrial optimization

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Abstract
The synergy between scheduling and cutting stock optimization becomes increasingly important as industrial processes aim for increased efficiency and resource usage. This study is a general overview of the definitions, methodology, and approaches used in tackling the complications provided by the simultaneous consideration of scheduling and cutting stock problems by examining some current literature. This review intends to be a helpful resource for academics, practitioners, and decision-makers looking to understand these manufacturing processes and simplify operations by providing light on the developing landscape of research at this combination.

Keywords: Scheduling, cutting stock, combined, optimization, heuristic, metaheuristic

Introduction

The combination of scheduling problems with cutting stock problems has arisen as a critical topic of research in industrial optimization, where the pursuit of efficiency and resource use is vital. This review study takes a tour through some available literature to investigate the synergies and complications that arise when scheduling and cutting stock challenges are considered concurrently. With their numerous needs and limits, manufacturing processes require a detailed understanding of how these two important components interact to determine operational outputs.

As industries strive for greater competitiveness and sustainability, the integration of scheduling and cutting stock optimization becomes more than a theoretical question; it becomes a real need.

In light of this, the remainder of the paper is organized as follows: Section 2 gives a general overview of the production scheduling problems in the literature. Section 3 gives the definition and objectives of each type of problem, the integration, and the synergy between both problems. A review of some related works from the literature and a plethora of optimization techniques to tackle the combined problems, from exact algorithms to heuristic and metaheuristic approaches, are provided in Section 4. Finally, some conclusions are drawn, including a discussion of the future research directions for scheduling problems combined with cutting stock problems.

Production scheduling problems in the literature

Like many other OR application fields, scheduling theory research began in the early 1950s. Johnson's article [18] is regarded as a seminal work. It developed an efficient optimum technique and generalized some methods for exceptional cases [16]. Proposed many optimum rules for single-machine issues. These early papers formed the basis for much of the evolution of classical scheduling theory.

Later, scheduling problems were subjected to a variety of general optimization approaches. These included formulations for mixed and pure integer programming [24, 43, 6, 10, 9].

Dynamic programming [13, 20, 30], and branch and bound procedures [15, 23, 27].

Meanwhile, heuristic techniques for recognized computationally challenging tasks were being developed [34]. By the late 1960s, scheduling theory had a significant corpus [8].

Theoretical studies on problem complexity began in the 1970s [21]. It aims to optimize operational operations to pursue one or more goals by using existing production data, which may include previous scheduling outcomes. It was discovered that most real-world scheduling issues are mathematically classified as NP-hard problems for which no polynomial-time method is likely to exist [29]. For these situations, fast optimum algorithms are unlikely to exist. The efficacy of heuristic algorithms was investigated using theoretical analysis and computer experimentation.

We can summarize that there are three types of search algorithms for scheduling problems: exact algorithms, approximation algorithms, and heuristic algorithms.

- The exact approach is a full enumeration search that finds all possible solutions in the solution region. This algorithm will provide the best result. The exact approach has a restricted implementation regarding processing time for large-scale problems.
- Branch and bound is an exact algorithm. An approximation algorithm is a search method that employs mathematical formulation to guide the search direction to discover a good, feasible solution.
- A heuristic algorithm is a search method that employs certain rules to find a feasible solution in a solution area. Heuristic search is divided into two categories: building heuristics and improvement heuristics [19, 39]. The construction heuristic is a heuristic search that begins with an empty schedule solution set and adds one task to the scheduled solution set in each iteration until all jobs are scheduled. Improvement heuristic search is a heuristic search that begins with a full schedule that is created randomly or according to a certain dispatching rule, and the schedule solution set is improved in each iteration until a given stopping condition is met. Genetic algorithm (GA), Simulated annealing (SA), Tabu search (TS), and Adaptive search (AS) are improved heuristic search algorithms.

The reason for using approximation or heuristic search is that it takes significantly less computing time, even though this search can only provide decent solutions, which is optimal if we are lucky. If the precise technique is used, approximation and heuristic search are useful for large-scale issue sizes, especially for NP-hard problems.

A general overview of the cutting and scheduling problems

Definition

The cutting stock problem (CSP) and the scheduling problem (SP) pose well-known challenges in combinatorial optimization. The cutting stock problem, falling under the cutting and packing category, aims to minimize waste by efficiently cutting raw materials into smaller pieces to fulfill orders. In simpler terms, it involves determining how to cut a maximum number of smaller elements from a given material while using the least amount of the primary material. On the other hand, the scheduling problem is a decision-making process that addresses resource allocation over time to execute a set of tasks and achieve specific objectives, such as minimizing completion time [26].

In scheduling, operations are allocated to resources over time to optimize a criterion, involving both a set of resources and a set of consumers [38].

Both the cutting stock and scheduling problems are integral to various industries, necessitating optimal decision-making for effective resource allocation and task arrangement to ensure efficient operations.

Therefore, the cutting stock combined scheduling problem extends beyond these individual challenges. It involves determining a set of feasible cutting patterns that cover the demand for items and specify the times at which each pattern should be cut. The overarching goal is to minimize the total number of bins and production costs, including job flow time and makespan-related labor time. This integration aims to provide a comprehensive solution that optimizes both the cutting and scheduling aspects, ensuring efficient resource utilization and task arrangement in diverse industrial applications.

Integration of scheduling problems (SP) and cutting stock (CSP)

The integration of scheduling problems and cutting stock problems is a pivotal convergence in the domain of manufacturing optimization. Scheduling problems entail the strategic allocation of resources and time within production processes, while cutting stock problems focuses on the optimal utilization of raw materials by efficiently cutting them to meet specific demand requirements.

This synergy becomes especially significant in industries where materials undergo multiple cutting operations before assembly. Achieving optimal integration involves aligning the intricate scheduling framework with the complexities of cutting stock processes, ensuring that raw materials are cut optimally to fulfill production demands and minimize waste. Recent years have witnessed a surge in mathematical models addressing integrated/combined/coupled/ issues, emphasizing the interdependence of choices for a comprehensive solution. Coupling approaches, frequently adapted in specific industrial applications like clothing, glass, furniture, and paper sectors, are explored in-depth in the literature. Despite extensive discussions on production scheduling (CSP) and cutting stock problems (SP) individually, there is a notable gap in addressing their combined challenge. As articulated by [17], the efficiency of manufacturing processes relies on internal factors and interactions between adjacent processes. The contribution of optimal operations to overall plant performance is compromised if adjacent processes are less efficient. Researchers and practitioners recognize the importance of this integration, often employing a combination of classical scheduling algorithms and cutting stock optimization techniques to synchronize processes, minimize material waste, and enhance overall manufacturing efficiency.

Related works

The cutting stock problem is a well-known combinatorial optimization problem from the cutting and packing discipline that finds use in various industries and other contexts, including computer science, telecommunications, and logistics. As well as the scheduling problem is also a combinatorial optimization problem. While these problems are NP-hard, many recent contributions have been provided in the literature, including exact solution approaches, lower bounding procedures, and heuristic approaches. However, despite the progress in solving large-scale instances of these standard problems, many variants incorporating constraints arising in specific contexts still need to be explored. One of these variants combines the standard objective of the cutting stock problem (minimizing the number of raw materials used) with the scheduling problem (penalizing the delay of cutting operations).

The standard cutting stock problem (CSP) ignores production planning and scheduling for numerous customer orders, which are treated separately and sequentially. The scheduling problem SP is first solved, and the CSP is subsequently solved. However, in real-world industrial settings, customer orders must be planned and scheduled overtime to satisfy demand and mandated deadlines. If the cutting procedure is economically relevant, this strategy may raise the total cost. As a result, researchers began to examine combining these two problems [5]. were among the first to develop an integrated cutting model in a corrugated factory that considers the downstream workstations' capacity and processing time (printing, folding, and assembly) not only to minimize the cutting losses process but also to ensure that delivery dates are met. Later, in 1988 [11], published a study on CSP combined with the planning and scheduling problems in the clothing industry in order to find a coherent model of the problems related to the organization and the production theory.

In 1991 [46], suggested a heuristic for sequencing cutting patterns as one of the first approaches to tackling the integration of cutting stock and scheduling problems. Then, [22] provided a model for a multistage, two-dimensional CSP that considers due dates and release dates, in which orders are planned before the cutting process begins. The author solved the two-dimensional problem with varying lengths and widths of stock rolls. A task is a set of items to be cut with varying sizes, releases, and deadline dates. The author provides various integer-programming models for the issue of cutting patterns related to time and explains various Linear Programming (LP) and non-LP-based heuristics for generating suitable cutting patterns and schedules. However, this formulation is independent of the length of the periods because an optimal solution of the model may not be the optimal solution for the global problem.

In the same year [14], studied an analogous problem that arose in the actual world of the copper industry, but they did not handle it in a combined way, instead opting for a two-stage solution approach [40].

Offer a binary linear program (BLP) to maximize the total length of the converted corrugated board and minimize the trim loss in a single shift by considering just the WIP buffer as one large area and only one setup in every shift. Then, in 2000 [4] took up and ameliorated this study, including the CSP, buffer utilization, and machine loading problems with multiple setups per shift.

In the literature, the integration of CSP and production planning has taken two paths. In the first, the CSP is extended to a multiperiod context in which customer orders are delivered at a specific time, and inventory is kept for subsequent periods. The goal is to minimize a weighted total of output, trim loss, and inventory expenses. This is known as the combined cutting stock and lot sizing problem. It is more prevalent in make-to-stock production environments, where many authors have been interested in this direction for example [32, 12, 42, 36, 25, 33, 41, 35, 28], Etc.

In contrast, in the second path, the CSP is extended to a multiperiod context in which customer orders are completed in a make-to-order method. Because an order may take numerous periods to complete, scheduling multiple orders is important. In this scenario, the goal is to minimize trim loss from the cutting process and a criterion linked to order scheduling, such as the makespan or overall tardiness, known as cutting stock and scheduling problems (CSSP). In a more basic way, the objective of the CSSP is to find a sequence for the cutting patterns and the related frequencies in which the obtained cutting patterns are to be cut, taking into account the conflicting objectives of both problems, and respecting the resource constraints [1].

Introduced an integer linear programming model that incorporates the cutting process in the first production stage with part assembly in the second stage. In contrast, [45] proposed an integer-programming model for pattern sequencing considering the number of open stacks [37].

Suggested a model for scheduling patterns in a one-dimensional CSP with due dates based on assigning cutting patterns to periods. The authors investigate a column generation-based formulation for the problem. Their goal was to find a set of cutting patterns and a cutting sequence to minimize material waste while meeting order demands on time [2].

Analyzed the model presented by [37] and showed that when the latter is not reached by an early due date first rule, it may fail the optimal solution of the problem. Also, to solve this problem more effectively, they developed a heuristic based on the branch-and-price method. Similarly, [7] suggested scheduling customer orders with due dates and homogeneous orders in a one-dimensional CSP.

Then, as continued research, [3] proposed a new IP model for the same problem and a heuristic approach to solving it. The aim function was a weighted mixture of the number of bins and the maximum lateness.

Prompted by the textile environment, [44] proposed a mathematical model for CSSP with sequence-dependent setup times in terms of knife positions in a recent study, where each insertion and/or removal in the knives takes time to process. The authors provide a sequential heuristic for solving real-size instances and use the mathematical formulation to solve small instances. As well, in order to minimize the lateness, they developed a metaheuristic approach to solve the 2DBP with due dates.

Recently, [31] proposed a nonlinear integer programming (NIP) model and a genetic algorithm (GA) for the 2D guillotine cutting stock problem and the scheduling problem in the printing industry.

Conclusion

In conclusion, this review paper has delved into the intricate realm of industrial optimization, explicitly focusing on integration scheduling problems with cutting stock challenges. The synergy between these two critical components in manufacturing and resource allocation has been explored, shedding light on the complexities and innovative solutions within this interdisciplinary domain. Through an analysis of some existing literature, we have identified common threads, methodologies, and areas of progress in addressing the simultaneous considerations of scheduling and cutting stock problems.

In addition, we defined the cutting stock problem, rooted in cutting and packing, and the scheduling problem, which revolves around resource allocation over time, as undeniably crucial in diverse industries. The amalgamation of these challenges in the cutting stock combined scheduling problem has been highlighted, emphasizing the need for efficient cutting patterns and optimized task scheduling to minimize production costs and enhance overall operational efficiency.

As industries strive for increased competitiveness and sustainability, the insights provided by this review aim to serve as a resource for researchers, practitioners, and decision-makers navigating the complexities of industrial optimization. The exploration of synergies between scheduling and cutting stock challenges not only contributes to the academic understanding of these problems but also offers practical implications for improving real-world manufacturing processes.

The integration of scheduling problems and cutting stock problems presents a rich area for future research, offering opportunities for innovation and advancement in manufacturing optimization. Several avenues can be explored to enhance the effectiveness and applicability of integrated solutions, like developing methodologies for real-time integration that can dynamically adjust schedules and cutting patterns based on evolving production conditions, unexpected disruptions, or changes in demand, which requires the incorporation of real-time data analytics, the IoT (Internet of Things), and adaptive algorithms. Also, developing algorithms that can handle multiple competing objectives will provide more robust and flexible solutions by exploring multi-objective optimization techniques that consider conflicting objectives, such as minimizing makespan, reducing material waste, and balancing workloads.

As well as combining traditional optimization methods with heuristic and metaheuristic approaches to create hybrid optimization algorithms that can leverage the strengths of both types of methods, providing efficient solutions for complex scheduling and cutting stock scenarios. Etc.

Overall, future research in the integration of scheduling problems and cutting stock problems should address the complexities of modern manufacturing environments while considering advancements in technology, sustainability, and the evolving needs of diverse industries.

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