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Hybrid genetic optimization for solving the batch-scheduling problem in a pharmaceutical industry ☆

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ABSTRACT

In today's manufacturing outlook, production planning and scheduling may represent a leading leverage to enhance the competitiveness of firms which aim to address the new challenge coming from emerging markets and globalization. In this paper a real-world parallel machines scheduling problem from the pharmaceutical environment has been tackled. Though in the last decades literature extensively approached such an issue, a set of constraints and compulsory dispositions strongly increase the complexity of the level of the problem in hand; thus, in order to fulfill the firm's objectives in terms of production rate increase and rapidity of solution, a dedicated hybrid genetic algorithm equipped with a two-stage encoding and a proper local search has been developed. A twofold validation procedure has been adopted for the proposed optimization technique. First, it was compared with a set of meta-heuristic algorithms on the basis of a real-world data set. Once the outperformance of the proposed genetic optimization was demonstrated, a further comparison with a set of empirical schedules, manually performed by the production supervisor, had been carried out.

1. Introduction

Nowadays firms have to tackle an ever increasing global competition as well as an ever changing market demand fluctuation. Such a stressing condition pushes firms to continuously improve the performance of their production processes as to deliver the finished products as early as possible and at the lowest production cost. Scheduling optimization methods play a key role in manufacturing performance improvement and cost reduction and, as a consequence, they may represent a leading leverage in increasing firms' competitiveness.

Since most industrial scheduling problems are highly combinatorial and involve complex decision-making issues, they rarely can be optimally solved in a reasonable amount of time. Further, the computational effort to find a good solution is strongly dependent on the problem size itself. Although mathematical formulations are able to describe a large number of scheduling problems, in practice, they can only solve problems of modest size in a reasonable computational time (Kopanos, Mendez, & Puigjaner, 2010), thus highlighting their vulnerability against most real-world problems. According to Hermann (2006), algorithms that can find optimal solutions to these hard problems in a reasonable amount of time are unlikely to exist.

However, in the last decades, two different research streams concerning the optimization of real-life scheduling problems have captured the attention of both practitioners and scholars. The former consists of the integration between heuristics and mathematical programming models, as demonstrated by the following literary contributions.

Kopanos et al. (2010) proposed a mixed integer programming-based decomposition strategy to cope with a scheduling problem of a multi-stage pharmaceutical process. Their solution strategy approach entails a MIP-based core and consists of two major procedures: the constructive step and the improvement step. The objective of the former step is the generation of a feasible schedule in a short amount of time. Afterwards, the obtained schedule is gradually improved by implementing some elaborate rescheduling techniques by the latter step. Similarly, Stefansson, Sigmarsdottir, Jensson, and Shah (2011) used the decomposition-based approach to face a real-world scheduling problem related to the packing stage of a pharmaceutical company. After a thorough analysis of the process flow, they observed that there was a very critical bottleneck in the overall production process at the last stage, i.e.

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packing. Thus, because of the limited capacity at that stage, the problem was decomposed into two main components, one of which involving the single packing stage. The aim of their study was to compare the discrete and continuous representations for solving the individual parts of the decomposed problem. The optimality of the linear programming approach for small-size problems was exploited by Lin and Liao (2012), who studied the batch-scheduling problem for an assembly shop in a machinery factory. As concerns both medium- and large-size problems they compared three distinct heuristics, and confirmed the effectiveness of a properly developed batch family sorting heuristic also by means of a real-life implementation. Missbaurer, Hauber, and Stadler (2009) implemented an integrated approach involving linear programming along with heuristics for a scheduling system from the steel-making industry. In this research an LP model has been embedded within a properly developed heuristic procedure with the aim of iteratively improving each obtained schedule. Extensive numerical tests with real-life data demonstrated the effectiveness of the proposed scheduling tool. Another significance example of integration between mixed integer programming and evolutionary algorithms was provided by Sand et al. (2008) who made full use of a stage decomposition-based hybrid algorithm to deal with a realistic batch scheduling problem with uncertain data.

The second research stream gathers tailor-made heuristics and metaheuristics algorithms able to find near-optimal solutions through a quick and at the same time smart exploration of the solution space. Since real-life scheduling problems are usually characterized by several constraints emphasizing their complexity with respect to the theoretical models usually approached by literature, metaheuristic techniques may represent a valid and versatile alternative to quickly solve such combinatorial issues. In fact, metaheuristic algorithms do not require any mathematical programming modeling, but their efficacy and efficiency strongly depend on the problem encoding as well as on the way a given problem code is decoded to generate a feasible solution of the problem itself. Several excellent contributions mentioning the application of meta-heuristic optimization algorithms to real-life industrial scheduling issues are reported in the following paragraphs.

Pearn, Chung, Chen, and Yang (2004) investigated a case study on the multistage integrated-circuit final testing scheduling problem, wherein jobs are clustered by their product types, and they must be processed on group of parallel machines. The job processing time depends on the product type and the machine setup time is sequentially dependent on the orders of processed jobs. They presented three fast network algorithms to efficiently solve the scheduling problem and provided a performance comparison among the proposed techniques on eight test problems.

A simulated annealing algorithm was implemented by Loukil, Teghem, and Fortemps (2007) for addressing a real-case production scheduling problem in a flexible job shop with particular constraints. Indeed, the authors arranged a multi-objective SA in order to yield efficient schedules in terms of: makespan, mean completion time, maximum tardiness and mean tardiness.

A job shop case study from the apparel industry was approached by Guo, Wong, Leung, Fan, and Chan (2006) through a genetic optimization technique. In order to properly tackle the mixed- and multi-product assembly environment under investigation, authors adopted a new chromosome representation and equipped the genetic engine with a heuristic initialization process and with modified crossover and mutation operators as well. Another demonstration about the leading role of expert systems in real-world manufacturing arises from the study of Soyuer, Kocamaz, and Kazancoglu (2007), wherein a scheduling tool based on a unique constructive algorithm has been developed to manage the short-term production planning of a firm producing copper wires. The hierarchical procedure provided the by authors revealed its applicability and optimality in solution.

Soman, Van Donk, and Gaalman (2007) presented a combined production planning and scheduling framework for a food processing company. Since the short-term batch-scheduling problem plays a key role in the proposed conceptual framework, a proper heuristic algorithm to solve that problem has been developed.

The wirebonding scheduling issue, which basically consists of an equal parallel machine scheduling problem, has been approached by an evolutionary simulation-optimization technique (Yang, 2009). The effectiveness of the proposed optimization strategy was confirmed by comparing the empirical results with a set of lower bound solutions.

Jia and Mason (2009) compared a set of polynomial – time heuristics approaches for investigating the identical parallel machine scheduling problem related to a semiconductor manufacturing process. Although a mixed integer programming model was generated for the problem in hand, a heuristic based approach was required to solve the problem in a satisfactory amount of time. An experimental analysis made the authors able to identify the most promising heuristic procedure to cope with this practically motivated scheduling problem.

Another application of metaheuristics techniques is ascribable to Venditti, Pacciarelli, and Meloni (2010), who studied a packaging department of a pharmaceutical industrial plant. They modeled the problem as a multi-purpose machine scheduling problem with setup and removal times, release and due dates and additional constraints related to the scarce availability of tools and operators. In particular, they developed a proper tabu-search algorithm, whose objective was minimizing both makespan and maximum tardiness in lexicographic order.

He and Hui (2010) tackled the scheduling problem related to a typical multi-purpose batch plant with a network structure. Since mathematical programming is not able to solve large-sized issues, the authors proposed a genetic algorithm (GA) equipped with a binary encoding. Due to the logical heuristics utilized to decode a chromosome into a schedule, only feasible solution space is searched. Comparative studies performed by authors show as their technique takes much shorter search time for the proposed algorithm to obtain the optimal solutions for both small and medium instances with respect to the MILP model. On the other hand, the same algorithm solved the large-sized instances obtaining good quality solutions within a very short time.

Huang, Cai, and Zhang (2010) addressed a real-world scheduling problem on parallel dedicated machines in which setup times are sequence dependent and setup operations are performed by a single server. A hybrid genetic algorithm was developed and tested on the basis of a comprehensive data set from a printing industry.

More recently, Meeran and Morshed (2012) coped with a job shop scheduling problem related to a real machining department. In order to efficiently solve the problem under investigation, the authors implemented a novel hybrid genetic tabu search, namely an integrated technique that combines the diversified global search and intensified local search capabilities of GA and TS, respectively. Again in the field of the parallel machine scheduling problem, Chen, Cheng, Wang, and Chen (2013) studied a solar cell industry which is similar to the traditional hybrid flow shop (HFS) scheduling problem. Since the challenge in solar cell manufacturing is allocating sublots to parallel machines of each stage such that the makespan time is minimized, a hybrid approach based on the Variable Neighborhood Search and particle swarm (VNPSO) was implemented to obtain the near-optimal solution. Preliminary computational studies demonstrated that the metaheuristics algorithm proposed by the authors provides good quality solutions in an acceptable amount of time and also outperformed the classic