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Technical Paper

Hybrid simulation and MIP based heuristic algorithm for the production and distribution planning in the soft drink industry

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ABSTRACT

This study addresses the production and distribution planning problem in the soft drink industry. The problem involves the allocation of production volumes among the different production lines in the manufacturing plants, and the delivery of products to the distribution centers (DCs). A mixed integer linear programming (MILP) model is developed for the problem.

In this paper, we present a hybrid solution methodology combining simulation and mixed integer programming (MIP) based Fixed and Optimize heuristic to solve the considered problem. First, MIP based Fix and Relax (F&R), Fix and Optimize (F&O) heuristics are proposed. The solution quality and performance of the proposed heuristics are analyzed with the randomly generated demand figures for the three granularity categories and various capacity load scenarios. Computational performances of these heuristic procedures are compared with the standard MIP results. The computational experiments carried out on a large set of instances have shown that the F&O heuristic algorithm provides good quality solutions in a reasonable amount of time. Second, simulation model is introduced to represent the problem with stochastic machine failures. Hybrid methodology combining the MIP based F&O heuristic and simulation model is implemented. The optimization model uses an F&O heuristic to determine the production and delivered quantity. Subsequently the simulation model is applied to capture the uncertainty in the production rate. Numerical studies from the data which have a tight production capacity and high demand granularity demonstrate that the developed hybrid approach is capable of solving real sized instance within a reasonable amount of time and demonstrate the applicability of the proposed approach.

1. Introduction

In recent years, the achievement of effective supply chain operations to avoid excessive inventories and operation costs depends on closer coordination of production and distribution activities. MIP is a popular optimization approach in the literature to model this coordination. Due to the extensive and complex nature of organization, MIP techniques may not have acceptable solution times for a wide range of real case applications. To overcome this obstacle of MIP technique for larger problem size, the MIP based heuristics emerge as promising solution methodologies.

Our research is motivated by the production–distribution planning problem encountered by a soft-drink company, which has to decide routinely the quantity produced and, the best way of delivering a set of orders to its customers over a multi-day planning horizon. The problem is formulated as an MILP model, which is an extension of the formulation previously studied by Bilgen [1]. The model is extended to account for backordering. Two rolling horizon heuristics, namely F&O, and F&R are used to solve the model.

In this paper operation times in the MILP model are considered as the dynamic factor and adjusted by the results from independently developed simulation model. Hybrid MIP based heuristic and simulation model are aimed at combining the strength of MIP based heuristic and the simulation model and reducing the impact of limiting characteristics of these models. Iterative use of MIP based heuristic and simulation methodologies exploit the benefit of obtaining optimal solutions, while revealing the impact of operation time uncertainty on system performance.

The main contributions of this paper are (i) implementation of the MIP based rolling horizon heuristics to the production allocation and distribution planning problem, (ii) propose a hybrid approach that combines simulation and MILP based F&O heuristic in an iterative process in order to gain the advantages of MILP based heuristics and simulation to minimize the overall cost for the considered problem.

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The remainder of this paper is organized as follows. The relevant literature is reviewed in Section 2. In Section 3, the key characteristics of the problem are outlined, and the MILP model is described in detail. The solution approaches are described in Section 4. Numerical results are presented in Section 5. Conclusions and directions for further work are discussed in Section 6.

2. Literature review

The efficient coordination of production and distribution systems becomes a challenging problem as companies move toward higher collaborative and competitive environments. In the literature, integrated production and distribution planning problem has been subject of many studies during the last decade. Interested readers are referred to [2–7] for a complete review of production and distribution models in supply chain environments. In the last decade, several models which address the supply chain coordination issues at different decision levels are developed (e.g. [8–14]).

In this section we review the most relevant and recent literature on MIP based heuristic applications and application of hybrid analytic and simulation modeling approach to the production and distribution planning problem.

2.1. Literature on MIP based heuristics

In terms of the solution procedures, the common MIP based heuristics, which are widely used in the literature, are F&R and F&O. The applications of these MIP based heuristics fundamentally focus on the production planning, lot-sizing and scheduling problems.

2.1.1. F&R heuristic

F&R approach is originally described as a time decomposition heuristic by Dillenberger et al. [15]. There are various extensive F&R studies concerning the lot sizing and scheduling applications in the literature (e.g. [15–26]). Stadtler [16] considers a dynamic multi-item multi-level lot-sizing problem. He solves the problem on a rolling basis by adding later periods and removing the earlier ones. Kelly and Mann [17] present a methodology using relax and fix (R&F) decomposition heuristic with a constraint dropping strategy on a lot sizing problem. Absi and Kedad-Sidhoum [18] propose new MIP-based heuristics to address a multi-item capacitated lot sizing problem (CLSP) with setup times that arises in real world production planning context. de Araujo et al. [19] develop an R&F procedure to solve lot sizing and scheduling model that considers backorders and sequence dependent setup costs and times for group changeovers. Federgruen et al. [20] present a so called progressive interval heuristic for the CLSP with joint setup cost. Beraldi et al. [21] present a new rolling horizon and F&R heuristics for the single machine and identical parallel machine CLSP with sequence dependent setup costs. Pochet and Warichet [22] present a continuous time MILP formulation for the cyclic scheduling. de Araujo et al. [23] consider lot sizing and scheduling problem in a manufacturing plant for animal feed compounds. R&F approach is developed to solve the problem. Akartunalı and Miller [24] present a heuristic framework that can generate high quality feasible solutions quickly for various kinds of lot sizing problems. Ferreira et al. [25] introduce a MIP model that integrates the production lot sizing and scheduling decisions of beverage plants with sequence dependent setup times and costs. A relaxation algorithm and various R&F strategies that explore the model structure are proposed and used to solve real instances of the problem. Mohammadi et al. [26] consider the multi-product multi-level CLSP with sequence dependent setups. Four variants of F&R heuristics are developed. F&R heuristic is the most widely applied in production planning, in particular lot sizing and scheduling problems. In addition to F&R heuristic applications on lot sizing and scheduling problem, there are few papers that use F&R heuristic on supply chain planning problems. Ouhimmou et al. [27] present a mathematical model for furniture supply chain planning problem. They develop a heuristic using a time decomposition approach. Alonso-Ayuso et al. [28] and Alonso-Ayuso et al. [29] consider a multi-period single-sourcing supply chain problem under uncertainty. Uggen et al. [30] have applied F&R time decomposition heuristics to solve the maritime inventory routing problem, and this is a new approach for this problem class. Table 1 summarizes the relevant literature in a systematic manner to clarify the application areas of the F&R heuristic algorithm.

2.1.2. F&O heuristic

Pochet and Wolsey [31] describe an improvement heuristic similar to the R&F heuristic, which they called "exchange" heuristic. The same approach is used in Sahling et al. [32] and Helber and Sahling [33] for the multi-level CLSP, where the authors called it the F&O heuristic [34]. James and Almada-Lobo [34] integrate F&O in a stochastic local search algorithm to improve the initial solution obtained with the R&F heuristic, delivering solutions within a small deviation from theoretical lower bounds to solve the CLSP problem with sequence dependent setup times and costs in single and multi-machine settings.

The F&O heuristic is introduced by Sahling et al. [32], Helber and Sahling [34] for solving the dynamic multi-level CLSP with setup carry over. Their algorithm solves a series of MIPs in an iterative F&O approach. Helber and Sahling [33] present an optimization based solution approach for the dynamic multi-level CLSP with positive lead times. Lang and Shen [35] consider a capacitated single-level dynamic lot-sizing problem with sequence-dependent setup costs and times that includes product substitution options. They develop a MIP formulation of the problem and introduce MIP-based F&R and F&O heuristics. More recently, Helber et al. [36] present a stochastic version of the single-level, multi-product dynamic lot-sizing problem subject to a capacity constraint. They use an adapted version of the flexible F&O heuristic proposed by Helber and Sahling [33].

The last few years have seen increasing interest and efforts in the integration of MIP based heuristics and the other metaheuristics. Goren et al. [37] introduce a novel hybrid approach by combining genetic algorithms and an F&O heuristic to solve the CLSP with setup carryover. Seeanner et al. [38] present an improvement heuristic based on the principles of the Variable Neighbourhood Decomposition Search (VNDS) and F&O to solve multi-level lot-sizing and scheduling problems. Toledo et al. [39] propose a multi-population based metaheuristic using F&O heuristic and mathematical programming techniques to solve the multi-level CLSP with backlogging. Stadler and Sahling [40] present a new model formulation for lot-sizing and scheduling of multi-stage flow lines which works without a fixed lead-time offset. They present a solution approach based on F&R and F&O. Ghaderi and Jabalameli [41] formulate the multi-period health care facility location problem as a budget-constrained model. A greedy heuristic and an F&O heuristic based on simulated annealing and exact methods are proposed to solve the model. Guimaers et al. [42] present a novel mathematical model and a mathematical programming based approach to deliver superior quality solutions for the single machine CLSP problem with sequence-dependent setup times and costs. They propose a solution approach, based on a large bucket sequence related model, integrates column generation in R&F and F&O schemes. Xiao et al. [43] examines CLSP with sequence-dependent setup times, time windows, machine eligibility and preference constraints. Two MIP-based F&O algorithms are proposed.

Table 2 summarizes the relevant literature in a systematic manner to clarify the application areas of the F&O algorithm and displays that production planning, inventory planning and supply chain management are promising areas for the future research.