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A robust optimization model for multi-product two-stage capacitated production planning under uncertainty

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ABSTRACT

Production planning (PP) is one of the most important issues carried out in manufacturing environments which seeks efficient planning, scheduling and coordination of all production activities that optimizes the company's objectives. In this paper, we studied a two-stage real world capacitated production system with lead time and setup decisions in which some parameters such as production costs and customer demand are uncertain. A robust optimization model is developed to formulate the problem in which minimization of the total costs including the setup costs, production costs, labor costs, inventory costs, and workforce changing costs is considered as performance measure. The robust approach is used to reduce the effects of fluctuations of the uncertain parameters with regards to all the possible future scenarios. A mixed-integer programming (MIP) model is developed to formulate the related robust production planning problem. In fact the robust proposed model is presented to generate an initial robust schedule. The performance of this schedule could be improved against of any possible occurrences of uncertain parameters. A case from an Iran refrigerator factory is studied and the characteristics of factory and its products are discussed. The computational results display the robustness and effectiveness of the model and highlight the importance of using robust optimization approach in generating more robust production plans in the uncertain environments. The tradeoff between solution robustness and model robustness is also analyzed.

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1. Introduction

Production planning is one of the most significant issues carried out in manufacturing systems which seeks efficient planning, scheduling and coordination of all production activities that optimizes the company's objective. The goals of production planning are determining the optimal quantity of production, inventory and other manufacturing parameters to satisfy fluctuating demands over a planning horizon [1]. Production planning has taken substantial attention in operations research literature. Some researchers have used a hierarchical approach for production planning that called hierarchical production planning (HPP). Hierarchical production planning is a renowned approach to handle the complexity of multi-level production planning and scheduling problems in real-world systems [2,3]. Other researchers have used multi criteria decision making (MCDM) approaches for production planning [4,5]. Comprehensive surveys on production planning in the literature were provided to cover different assumptions of manufacturing environment [6–9]. Mula et al. [10] provided a profound review on mathematical models for production planning under uncertainty.

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Stadtler [11] considered dynamic multi-item multi-level lot-sizing problem in general product structures with single and multiple constrained resources as well as setup times. He proposed a relax-and-fix heuristic, called internally rolling schedules with time windows to solve the problem. Akartunali and Miller [12] studied multi-item multi-level production planning problems with backlogging. They developed a time window MIP based heuristic that can generate good quality feasible solutions in reasonable computational time for various kinds of lot-sizing problems. Wu et al. [13] proposed two new MIP models to formulate capacitated multi-level lot-sizing problems with backlogging. They developed an effective optimization framework that achieves good quality solutions in reasonable computational time. Wu et al. [14] studied the capacitated multi-level lot-sizing problem with setup times. They presented a developed relax-and-fix based heuristic that uses domains derived from several strategies of relax-and-fix and a LP relaxation technique. Ramezani et al. [15] studied a multi-product multi-period capacitated multi-stage production planning with sequence-dependent setups. They proposed a more efficient mathematical model for the problem and used two MIP-based heuristics for solving related problem.

Many real-world planning problems involve noisy, incomplete or inaccurate data. In the literature, different approaches have been used to deal with different forms of uncertainty. Mathematical programming and stochastic approaches were used to formulate uncertainty in manufacturing systems [16–18]. Another approach to incorporate uncertainty in production planning models is fuzzy approach [19–21]. Recently, robust optimization model, strong technique to contrast uncertainty, was used to deal with uncertainty in the systems. Robust optimization can be very efficient and useful because of generation of the good and stable solutions for any possible occurrences of uncertain parameters [22].

The concept of robust optimization in operation research is introduced by Mulvey et al. [22]. They developed a robust counterpart approach with a nonlinear regularization function that penalizes the constraint violations and uncertainties are addressed via a set of discrete scenarios. Robust optimization has yielded a series of solutions that are progressively less sensitive to realizations of the data in a set of scenarios. The optimal solution of robust optimization model will be robust with respect to optimality if it remains 'close' to the optimal if input data change: this is called *solution robustness*. The solution is also robust with respect to feasibility if it remains 'almost' feasible for small changes in the input data: this is termed *model robustness*. Bai et al. [23] showed that the traditional stochastic linear program fails to determine a robust solution despite the presence of a cheap robust point. They examined properties of risk-averse utility functions in robust optimization. They argued that a concave utility function should be incorporated in a model whenever the decision maker is risk averse. Ben-Tal and Nemirovski [24] proposed a robust optimization approach to formulate continuous uncertain parameters. Ben-Tal and Nemirovski [24], Ben-Tal and Nemirovski [25] and Ben-Tal et al. [26] developed robust theory of linear, quadratic and conic quadratic problems. Their approaches are used vastly in many engineering and design problems. Bertsimas and Sim [27] and Bertsimas and Thiele [28] proposed robust optimization methods for discrete optimization in continuous spaces.

Leung and Wu [29] considered aggregate production planning (APP) problem in which some parameters are uncertain. They proposed a robust optimization model to minimize total production cost in manufacturing systems. They analyzed their proposed model solutions with single-period and multi-period data and considered the tradeoff between solution and model robustness. Leung et al. [30] studied robust model for multi-site production planning problem. They applied their

Table 1
Main features of robust optimization models for production planning problem.

Features	Leung and Wu [29]	Leung et al. [30]	Leung et al. [31]	Kazemi Zanjani et al. [32]	The proposed model
Main topic	Robust aggregate production planning	Robust multi-site production planning	Robust production planning for perishable products	Robust sawmill production planning	Robust production planning for two-stage production system
No. of stages	Single-stage	Single-stage	Single-stage	Single-stage	Two-stage
No. of products	Multiple	Multiple	Multiple	Multiple	Multiple
No. of periods	Multiple	Multiple	Multiple	Multiple	Multiple
No. of machines	Single	Single	Single	Multiple	Multiple
Subcontracting	Considered	Considered	Not considered	Not considered	Considered
Workforce	Considered	Considered (k -types)	Considered (single type)	Not considered	Considered (2-types)
Labor hiring	Allowed	Allowed	Allowed	Not allowed	Allowed
Labor lay off	Allowed	Allowed	Allowed	Not allowed	Allowed
Backorders	Not included	Not included	Not included	Allowed	Allowed
Variation term	Absolute form	Absolute form	Absolute form	Quadratic form	Absolute form
Setup	Not considered	Not considered	Considered	Not considered	Considered
Lead time	Not considered	Not considered	Not considered	Not considered	Considered
Uncertain parameters	Demand, lay off cost, hiring cost, subcontracting cost	Demand, production cost, labor cost, inventory cost	Demand, regular time and overtime production cost, inventory cost	Units of products produced by processes (yield of processes)	Demand, regular time and overtime production cost, subcontracting cost, labor cost

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