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A novel integrated production-distribution planning model with conflict and coordination in a supply chain network

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ABSTRACT

In this paper, an integrated production-distribution planning model using bi-level programming is proposed for supply chain management. In the bi-level model, the core firm is the leader in the hierarchal process that decides which plants and warehouses to open to serve customers to minimize total global cost. In the lower level, the production branch and distribution branch managers aim to minimize costs in their respective branches and make decisions based on the core firm's decisions. A hybrid priority-based two stage genetic algorithm with a fuzzy logic controller algorithm is developed to solve the proposed model. Finally, construction material transportation at the Lancang River Hydropower Base is taken as a real world example to demonstrate the practicality and efficiency of the optimization model and the algorithm.

1. Introduction

A supply chain (SC), which is typically made up of suppliers, manufacturing plants, warehouses, and consumers, starts with the production of raw materials and finishes with product consumption. These days, due to increased global competition, almost all companies cooperate to decrease the risk of working alone. Globalization requires closer relationships between partners and more effective planning and configuring mechanisms for the SC [1,2]. However, as companies move toward higher collaborative and competitive environments, efficient coordination of the integrated production and distribution systems in an SC network has become a significant challenge.

The main focus of this paper is to model the integrated production-distribution (PD) control decisions by considering both the conflicts and coordination within the supply chain (SC). Readers can find a comprehensive review and critique of PD models from previous research [3–5]. In the last decade, several models which address SC coordination issues have been developed. Nasiri et al. [1] presented a hierarchical planning approach to develop a PD plan for a year-long planning horizon. Chen [6] investigated the effects of various factors related to item substitution strategies on two-echelon PD networks in decentralized SCs. Sabri and Beamon [7] developed a multi-objective SC model to enable both strategic and operational PD planning. In that research, the SC structure had four echelons: suppliers, plants, distribution centres, and customer zones. Liang [8] developed a fuzzy multi-objective linear programming model to solve integrated multi-product and multi-time period PD planning decision problems. From this previous research, several conclusions can be drawn: (1) Integrated PD problems have several echelons (participants), such as plants, distribution centres, and customers zones [1,6,7]; (2) Most research has used multi-objective analyses to deal with the PDs conflicted objectives [7–9].

In PD problems, many participant groups such as the plant, distribution centres, and customer zones collaborate for a certain period of time in a hierarchical system [1,6,7]. In actual construction projects, for example, there are decision making conflicts because the participants belong to different stakeholder groups, have different goals, and make decisions based on their own interests and aims [10]. These conflicts, however, can result in mutual influences, the results from which may significantly impact the PD planning. Most research has dealt with integrated PD problems using multi-objective analyses from one decision-maker who has different and conflicting objectives [7–9]. However, no mathematical models have yet been developed which have studied a PD problem involving more than one decision maker. Bi-level programming problems, which is introduced by Von Stackelberg [11], is a sequence of two optimization problems in which the constraints of the leader are determined by the solutions of the follower [12], namely more than one decision entity in a hierarchical structure. Developing PD systems that can eliminate conflicts and enhance coordination between the different managers (decision entities) are

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vital for supply chain efficiency, so bi-level programming (BP) can be very effective when seeking to coordinate such conflicted relationships. In this paper, a novel bi-level model is developed to describe the conflicts and improve the coordination between the participants in an integrated PD planning problem.

There are full of uncertainties in the real world. In order to provide solutions more suitable to actual production situations, uncertainties must be considered in the supply chain for the construction material distribution. Transportation costs and customer demands are often taken as uncertain variables [13]. The uncertainties of transportation costs are caused by uncertain travel and service times [14,15]. Based on the previous studies, travel times can be considered as not only stochastic variables [16] but also fuzzy variables [17], as well as customer demands, random [18,19] or fuzzy [20]. In Hu and Zhao's study, the expected utility model of retailers with the piecewise-linear loss aversion utility function is derived by the credibility measure of the fuzzy event, under the condition of fuzzy demand [20], whereas Giri and Sarker make an assumption that the demand at each retailer is random but influenced by the prices and service levels of both the retailer [19]. Further, it has been proved that fuzzy variables can be used to model ambiguous statistical data and past experience, while random variables can model stochastic factors [21]. For example, customer demands are usually acquired by survey or interview, and described as some ambiguous statements (fuzzy factors), such as "about at 2 ton" or "it is better no less than 1 ton"; In the mean time, some stochastic factors are involved too: (1) one point usually has more than one person in charge, the choice of respondents is stochastic; (2) due to some special reasons, such as season, whether, type of respondents (optimistic or pessimistic) etc., the customers usually give different demand quantities. That is to say, the statements of customer demands include both fuzzy and stochastic influencing factors. Consequently, in this paper, transportation costs and customer demands are assumed to be fuzzy random variables, which is believed to be closer to reality and is able to deal efficiently with complicated practical problems.

Genetic algorithms (GA), first developed by Holland based on the mechanics of natural selection in biological systems, are one of the most adopted heuristic solution methods [22]. GAs combine directed and stochastic search methods and are able to achieve a good balance between the exploration and exploitation of the search space [23]. GAs have been proven to be a highly effective and efficient tool for solving complex engineering and manufacturing problems and have been successfully applied to PD [23–25] and supply chain management problems [26–28]. A priority-based two stage method can be adapted for the GA for a PD problem, and to fine-tune the GA parameters, a fuzzy logic controller (flc) has also proved to be very useful [29]. Therefore, a hybrid priority-based two stage genetic algorithm with a fuzzy logic controller (hpts-GA with flc) is developed in this paper to solve an integrated PD problem that involves both conflict and coordination.

The main contributions of this paper are as follows. First, this paper proposes a new fuzzy random bi-level model which considers a two-level hierarchy in an integrated PD problem that has both conflict and coordination. Second, a hybrid priority-based two stage Genetic Algorithm with a fuzzy logic controller (hpts-GA with flc) and fuzzy random simulations is developed to solve this problem. Third, the proposed model and method are adopted to solve a practical case. This paper is organized as follows. In Section 2, the preliminaries for the bi-level programming and fuzzy random theoretical applications are given; then, the problem description for the integrated PD are given in Section 3. Section 4 gives the mathematical description for an integrated PD model with two subnetwork models. In Section 5, an hpts-GA with an flc is designed to solve the complex bi-level PD model. In Section 6, the proposed method is applied to a construction project at the Yalong River Hydropower Base in China. Some conclusions and future research suggestions are given in Section 7.

2. Preliminaries

2.1. Fuzzy random theory

For better understanding this paper, the basic knowledge of fuzzy random variables is stated. These results are crucial for the rest of this paper. The following will be used extensively.

Definition 2.1. [30] Given a domain X. If $\widetilde{A}$ is a fuzzy subset of X, for any $x \in X$, $\mu_{\widetilde{A}} \to [0,1], x \to \mu_{\widetilde{A}}(x)$, $\mu_{\widetilde{A}}$ is called a membership function of x with respect to $\widetilde{A}$, $\mu_{\widetilde{A}}$ denotes the grade to each point in X with a real number in the interval [0, 1] that represents the grade of membership of x. $\widetilde{A}$ is called a fuzzy set and described as $\widetilde{A} = \{(x, \mu_{\widetilde{A}}(x)) | x \in X\}$.

Definition 2.2. [30] Let X be a domain, and r is the possibility level and $0 < r \leq 1$. A_r consist of all elements whose degrees of membership in $\widetilde{A}$ are greater than or equal to r, and A_r is called the r-level set of fuzzy set $\widetilde{A}$ if $A_r = \{x \in X | \mu_{\widetilde{A}}(x) \geq r\}$.

Definition 2.3. [31] Let Θ be a nonempty set, and $P(\Theta)$ be the power set of Θ. For each $A \subseteq P(\Theta)$, there is nonnegative $Pos\{A\}$, called its possibility, such that

(1) $Pos(\emptyset) = 0$ and $Pos(\Theta) = 1$.
(2) $Pos(\bigcup_r A_r) = \sup_r Pos(A_r)$ for any arbitrary collection $\{A_r\}$ in $P(\Theta)$. The triple $(\Theta, P(\Theta), Pos)$ is called a possibility space. The function Pos is referred to as a possibility measure.

Definition 2.4. [32] A fuzzy variable is defined as a function from the possibility space $(\Theta, P(\Theta), Pos)$ to the real number R.

Definition 2.5. Let ξ be a discrete random variable defined on a probability space $(\Omega, \mathcal{A}, \Pr)$ with the discrete distribution $P_\xi(x) = P\{x = x_n\}$, $n = 1, 2, \ldots,$, and θ be any given probability level and $0 \leq \theta \leq \max P_\xi(x)$. ξ_θ consists of all elements whose value of $P_\xi(x)$ for ξ are greater than or equal to θ, $\xi_\theta = \{x \in R | P_\xi(x) \geq \theta\}$, then ξ_θ is called the θ-level set of random variable ξ.

In order to describe the phenomenon that contains random and fuzzy factors synchronously, Kwakernaak proposed the concept of fuzzy random variables for the first time in 1978 [33]. In this paper, considering the uncertain information appearing in the SC network, we choose the theory proposed by Kwakernaak [33] and further developed by Puri and Ralescu [34], to describe and deal with the uncertainty.

Definition 2.6. [34] Let $(\Omega, \mathcal{A}, \Pr)$ be a probability space, and $\mathcal{F}_c(R)$ a collection of fuzzy variables defined on the possibility space. A fuzzy random variable is a function $\tilde{\tilde{\xi}} : \Omega \to \mathcal{F}_c(R)$ such that for any $\gamma \in [0,1]$, $\tilde{\tilde{\xi}}_\gamma(\omega) = \{x | \mu_{\tilde{\tilde{\xi}}}(x) \geq \gamma, x \in R\}, \forall \omega \in \Omega$ is a measurable function of ω.

By Definition 2.6, a fuzzy random variable is a measurable function from a probability space to a collection of fuzzy variables. Roughly speaking, a fuzzy random variable is a random variable taking fuzzy values. In exceptional circumstance, if Ω consists of a single element, then the fuzzy random variable degenerates to a fuzzy variable. If $\mathcal{F}$ is a collection of real numbers, then the fuzzy random variable degenerates to a random variable.

2.2. Bi-level programming

Multilevel decision-making techniques, presented by multilevel mathematical programming, have been developed to address compromises between the interactive decision entities that are distributed throughout a hierarchical organization [35]. A BP is an