Knowledge-Based Systems 50 (2013) 14–24

Contents lists available at SciVerse ScienceDirect

Knowledge-Based Systems

journal homepage: www.elsevier.com/locate/knosys

Fourth party logistics routing problem model with fuzzy duration time and cost discount

Yan Cui [a,b], Min Huang [a,b,*], Shengxiang Yang [c,b], Loo Hay Lee [d,e], Xingwei Wang [a,b]

[a] *College of Information Science and Engineering, Northeastern University, Shenyang, Liaoning 110819, China*
[b] *State Key Laboratory of Synthetical Automation for Process Industries, Northeastern University, Shenyang, Liaoning 110819, China*
[c] *School of Computer Science and Informatics, De Montfort University, Leicester LE1 9BH, UK*
[d] *Department of Industrial and Systems Engineering, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260, Singapore*
[e] *Logistics Engineering College, Shanghai Maritime University, Shanghai 201306, China*

ARTICLE INFO

Article history:
Received 10 September 2012
Received in revised form 16 April 2013
Accepted 21 April 2013
Available online 9 May 2013

Keywords:
Fourth party logistics
Routing problem
Chance constrained programming
Memetic algorithm
Local search

ABSTRACT

In this paper, from the viewpoint of a fourth party logistics (4PL) provider, a multi-source single-destination 4PL routing problem with fuzzy duration time and cost discount (M-S 4PLRPFC) is described considering the comprehensive ability of 3PL suppliers and nodes. A chance-constrained programming model is established for the M-S 4PLRPFC. Next, a memetic algorithm (MA) with a fuzzy simulation method is designed to solve the problem. Based on a set of problem instances as the test bed, experiments are performed to compare the performance of the proposed MA with those of the enumeration method and a standard genetic algorithm (SGA). The experimental results show that the proposed MA obtains the same results as the enumeration method and that it is than the SGA.

1. Introduction

With the development of science and technology, many companies have outsourced their logistics to special logistics providers known as third party logistics (3PL). Trebilcock [23] showed that nearly 75% of the Fortune 500 companies have relied on 3PL services since 1996. Additionally, 83% of the top 500 manufacturers in the United States had already adopted 3PL by 2003 [16].

3PL has been widely accepted by many companies. However, most 3PL providers only provide transportation and warehousing services. The integration, operation and monitoring of the complex resources of the supply chain and the maximization of the current and long-term benefits of the supply chain members remains an open a question. The initial concept of fourth party logistics (4PL) was introduced by Accenture, which is an integrator that assembles the resources, capability, and technology of its own organization and other organizations to design, build, and run comprehensive supply chain solutions [2]. Because the essence and core superiority of 4PL lies in its ability to integrate the supply chain resources, it encourages strategic alliances among 3PLs and manages the logistic process within the entire supply chain. Many articles, such as [1,3,7,19,20], have discussed this concept, revealing that 4PL will likely surpass 3PL and become the main logistics service mode in the following years.

As 4PL plays an important role in modern logistics, many studies have been conducted on 4PL ever since its introduction. These studies can be classified into two classes, one regarding the perspective of 4PL, which focuses on its macro-framework, such as its historical inevitability, advantages, and development prerequisites [3,11,19,22]; and one regarding the optimization of operational problems under the guidance of 4PL, such as the 4PL routing problem (4PLRP) [4,12,13], the selection of 3PL suppliers [5,26], and the operational problems in the 4PL supply chain [14,15,24,25].

The routing problem is one of the most important issues in logistics and has received extensive attention from researchers over the past several decades. When studying the routing problem in 4PL, researchers found that it is more difficult than that in 3PL because more issues, such as the selection of 3PL providers, the cost and time factors, and the capacity and reputation of 3PL providers, should be considered. In recent years, the 4PLRP has attracted increasing attention from researchers. There have been studies in the literature that apply different intelligent methods to solve the 4PLRP. Chen et al. [4] proposed a genetic algorithm (GA) for solving the 4PLRP with ten nodes. Li et al. [15] introduced some main optimization processes in the logistics operation, including routing optimization, job decomposition, and job assignment, and depicted the relationships between these processes.

---

* Corresponding author at: College of Information Science and Engineering, Northeastern University, Shenyang, Liaoning 110819, China. Tel.: +86 24 83691272; fax: +86 24 83688608.

E-mail address: mhuang@mail.neu.edu.cn (M. Huang).

0950-7051/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.knosys.2013.04.020

Huang et al. [12] considered the node-edge property with three different scales and developed a mathematical model for the 4PLRP. They designed an immune algorithm embedded with the Dijkstra algorithm to solve the 4PLRP model developed. To enhance the capability of seeking optimum solutions, Huang et al. [13] also proposed a hybrid immune algorithm by combining the memory base with the immune operator, which was shown to be better than the original immune algorithm.

Many studies have been devoted to the 4PLRP, but some problems remain. In the previous studies, the parameters are fixed and deterministic, which is not realistic. In a real-world situation, the driving conditions could be affected by many factors, such as weather and human factors. In the traditional way, researchers tend to use the stochastic optimization methods. However, under some conditions, it is difficult to describe the parameters of the problem as random variables because of insufficient data [17]. For example, the duration time from one point to another is often not precise enough, e.g., "between 30 and 40 min", or "approximately 1 h". Generally, we can use fuzzy variables to address these uncertainty parameters. Additionally, all of the previous studies focus on the single-source single-destination problem, while in real-world situations, such simple models are rarely or never representative. Many large manufacturing enterprises need to assemble products with many parts, which may be made by their subsidiaries from different areas. Therefore, such enterprises will be more inclined to resort to powerful logistics, such as 4PL, to serve their needs and integrate the supply chain resources.

Under this condition, a real-world model is developed for the multi-source single-destination 4PLRP with fuzzy duration time and cost discount (denoted M-S 4PLRPFC) using the credibility theory, where the cost of 3PL suppliers or nodes is discounted when they undertake multiple tasks. In M-S 4PLRPFC, there is more than one 3PL provider between two nodes, so it can be considered as a constrained shortest path problem (CSPP) with multi-source and fuzzy parameters in a multi-graph.

The CSPP is a type of shortest path problem that includes some constraints on the route. Although the CSPP and the fuzzy shortest path problem (FSPP) have been studied over recent years, there have been no attempts to study them together, not to mention the fuzzy constrained shortest path problem (FCSPP) in a multi-graph. The primary reason may be the difficulty in addressing the infeasibility of a path and the comparison between fuzzy numbers. One approach to solving the CSPP is to utilize a kth shortest path algorithm, terminating with the first path that satisfies the constraint [8]. This approach is impractical when the terminal value of k is large. Therefore, it is not useful for solving the CSPP when there are many constraints.

Evolutionary algorithms are another way to solve the shortest path problems. Haghighat et al. [10] used the genetic algorithm (GA) approach to solve the multicast routing problem. Ghoseiri and Nadjari [9] provided an ant colony algorithm for the bi-objective SPP. Liu et al. [18] introduced the CSPP as an NP-hard problem and adopted an oriented spanning tree based the GA for solving the multi-criteria SPP as well as the multi-criteria CSPP. However, in our problem, there is usually more than one edge (3PL provider) that could be selected between any pair of nodes. It means that we need to get a shortest path in a multi-graph. Furthermore, for a multi-source SPP, the 3PL providers may be used more than once, which means that we need to determine whether a 3PL provider has left enough available ability to be selected. Thus, our problem is more complex than the CSPP.

In this paper, a real world M-S 4PLRPFC model is built by using the credibility theory [17], and a GA with a double arrays encoding method based on the fuzzy simulation method is designed. As the GA easily falls into a local optimum, it cannot find a satisfactory solution when the number of nodes increases to 30. Therefore, the performance of the GA is improved by an memetic algorithm (MA) by using a local search algorithm. To test the performance of the MA, numerical experiments are carried out to investigate the performance of the proposed algorithm on a set of 4PLRPFC instances. The results show that MA obtains the same results as the enumeration method (EA) and that it is better at solving the M-S 4PLRPFC than the GA is.

The rest of this paper is organized as follows. The next section introduces the credibility theory and describes the M-S 4PLRPFC and the process of the fuzzy simulation. Section 3 describes the proposed MA for solving the M-S 4PLRPFC in detail. Section 4 presents an experimental study investigating the performance of the proposed algorithm on some test M-S 4PLRPFC instances. Finally, Section 5 concludes this paper with some discussions on relevant future work.

2. Description of the M-S 4PLRPFC

In this section, the information of credibility space is first introduced. Then, the M-S 4PLRPFC is described. And last, fuzzy simulation method is developed according to the uncertainty theory.

2.1. Credibility space

Credibility theory was founded by Liu [17] as a branch of mathematics for studying the behavior of fuzzy phenomena. The emphasis is that credibility theory is based on following credibility measure. Let Θ be a nonempty set, and P the power set of Θ. Each element in P is called an event. In order to present an axiomatic definition of credibility, it is necessary to assign to each event A a number $Cr\{A\}$ which indicates the credibility that A will occur.

Definition 1. The set function Cr is called a credibility measure if it satisfies the following axioms:

Axiom 1. (Normality) $Cr\{\Theta\} = 1$.

Axiom 2. (Monotonicity) $Cr\{A\} \leqslant Cr\{B\}$ wherever $A \subset B$.

Axiom 3. (Self-Duality) $Cr\{A\} + Cr\{A^c\} = 1$ for any event A.

Axiom 4. (Maximality) $Cr\{\cup_i A_i\} = sup_i Cr\{A_i\}$ for any event $\{A_i\}$ with $sup_i Cr\{A_i\} < 0.5$.

Definition 2. Let Θ be a nonempty set, P the power set of Θ, and Cr is a credibility measure. Then the triplet (Θ, P, Cr) is called a credibility space.

Definition 3. A fuzzy variable is defined as a function from a credibility space (Θ, P, Cr) to the set of real numbers.

Definition 4. Let ξ be a fuzzy variable defined on the credibility space (Θ, P, Cr). Then its membership function is derived from the credibility measure by

$$\mu(x) = (2Cr\{\xi = x\}) \wedge 1, \quad x \in R$$

Membership function represents the degree of possibility that the fuzzy variable ξ takes some prescribed value. From credibility inversion theorem which was proved in [6], it has following formulation:

$$Cr\{\xi \in B\} = \frac{1}{2}(\sup_{x \in B} \mu(x) + 1 - \sup_{x \in B^c} \mu(x))$$

for any set of real numbers.

Definition 5. *(critical value)*: Let ξ be a fuzzy variable, and $\alpha \in (0,1]$. Then