Int. J. Production Economics 141 (2013) 199–211

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics

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

The selective pickup and delivery problem: Formulation and a memetic algorithm

Chuan-Kang Ting*, Xin-Lan Liao

Department of Computer Science and Information Engineering, National Chung Cheng University, Chia-Yi 62102, Taiwan

ARTICLE INFO

Article history:
Received 16 November 2011
Accepted 7 June 2012
Available online 26 June 2012

Keywords:
Pickup and delivery
Logistics
Evolutionary computation
Memetic algorithm

ABSTRACT

The pickup and delivery problem addresses the real-world issues in logistic industry and establishes an important category of vehicle routing problems. The problem is to find the shortest route to collect and distribute commodities under the assumption that the total supply and the total demand are in equilibrium. This study presents a novel problem formulation, called the selective pickup and delivery problem (SPDP), by relaxing the constraint that all pickup nodes must be visited. Specifically, the SPDP aims to find the shortest route that can supply delivery nodes with required commodities from some pickup nodes. This problem can substantially reduce the transportation cost and fits real-world logistic scenarios. Furthermore, this study proves that the SPDP is NP-hard and proposes a memetic algorithm (MA) based on genetic algorithm and local search to resolve the problem. A novel representation of candidate solutions is designed for the selection of pickup nodes. The related operators are also devised for the MA; in particular, it adapts the 2-opt operator to the sub-routes of the SPDP for enhancement of visiting order. The experimental results on several SPDP instances validate that the proposed MA can significantly outperform genetic algorithm and tabu search in terms of solution quality and convergence speed. In addition, the reduced route lengths on the test instances and the real-world application to rental bikes distribution demonstrate the benefit of the SPDP in logistics.

1. Introduction

The pickup and delivery problem (PDP) arises in many real-world cases such as logistics and robotics. This problem consists of several nodes classified as *pickup* customers and *delivery* customers. The former supplies while the latter demands a number of commodities. The goal of the PDP is to find the shortest route such that the requirement of each customer can be satisfied. Solving this problem concerns vehicle routing and commodity distribution. The PDP has been proved to be NP-hard. Several variants of the PDP consider different requirements for pickup and delivery customers, assumptions about the transportation scenario, and constraints on the transportation capacity. Berbeglia et al. (2007) conducted a comprehensive survey of PDP formulations and classified them into one-to-one, one-to-many-to-one, and many-to-many schemes.

Some real-world applications focus on supplying the demands of delivery customers. The constraint of visiting *all* pickup customers can, therefore, be relaxed by gathering sufficient commodities from *some* pickup customers. Such a relaxation can substantially reduce the transportation cost and still satisfy the demands of delivery customers. An example application is distributing rental bikes for city traveling, which is greatly promoted in tourism nowadays. The key is to arrange a route for the vehicle (truck) to transport bikes to the rental stations that have reservations and to the popular areas around the city. In this case, visiting all rental stations to pick up bikes is unnecessary; instead, picking up bikes from some rental stations and delivering them to the demanded places will be much more efficient.

This study formulates a new problem, called the *selective pickup and delivery problem* (SPDP), considering the above scenario. Distinguished from the PDP, the proposed SPDP holds two features: First, it relaxes the requirement for visiting all pickup nodes. Second, the SPDP imposes an additional constraint on the vehicle load. For the example of distributing bikes, the SPDP is to find the shortest route that can deliver all demanded bikes without visiting all pickup nodes. Furthermore, it avoids the impractical situation that a vehicle attempts to supply a delivery node with the number of bikes more than its load at some station or to hold a load exceeding its capacity. According to the classification of Berbeglia et al. (2007), the SPDP is of many-to-many scheme, where each node serves as either a source (pickup) or a destination (delivery) of commodities; and the commodities collected from pickup nodes can supply any delivery nodes.

* Corresponding author.
E-mail addresses: ckting@cs.ccu.edu.tw (C.-K. Ting), lhl99p@cs.ccu.edu.tw (X.-L. Liao).

0925-5273/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijpe.2012.06.009

To resolve the SPDP, this study proposes a memetic algorithm (MA) based on genetic algorithm and local search. Memetic algorithm is a blooming dialect of evolutionary algorithm (EA). In addition to *Darwinism*, MA implements *Lamarckian* or *Baldwinian* theory by integrating a local enhancement, such as local search and repair operator, into the canonical EA. This integration significantly improves the exploitation ability of EA and has been widely shown to provide superior solution quality and high convergence speed (Hart et al., 2004; Le et al., 2009; Meuth et al., 2009; Ong et al., 2006, 2007, 2010; Sinha et al., 2004). The proposed MA adopts a novel representation of candidate solutions to simultaneously deal with the selection of pickup nodes and the visiting order of nodes. A modified 2-opt operator is presented to improve the arrangement of visiting order. The fitness function, furthermore, helps to handle the constraint of vehicle load along the route. This study conducts a series of experiments to examine the MA performance on the SPDP. Furthermore, we apply the proposed method to a real-world rental bikes distribution problem.

The remainder of this paper is organized as follows. Section 2 reviews related work on the PDP. Section 3 presents the formal formulation of the SPDP and proof of NP-hardness. Section 4 sheds light on the proposed MA. The experimental results are presented and discussed in Section 5. Finally, we draw conclusions and recommend the directions for future work in Section 6.

2. Related work

The PDP aims for a minimum-cost route to distribute resources among nodes, including pickup nodes supplying commodity and delivery nodes requiring commodity. This problem can be viewed as a synthesis of the vehicle routing problem (VRP) and object distribution like the knapsack problem. In this study, we classify the PDP formulations according to the attributes of transportation, node, vehicle, and commodity. Table 1 summarizes many variants of PDP and their differences in the setting of these attributes. The first classification criterion—scheme—is proposed in the comprehensive survey of Berbeglia et al. (2007), where the PDP is categorized into one-to-one, one-to-many-to-one, and many-to-many schemes. The main difference among these three schemes is transportation endpoint (Parragh et al., 2008a,b): One-to-many-to-one schemes deliver commodities from the depot to linehaul customers and from backhaul customers to the depot (Gribkovskaia and Laporte, 2008), while one-to-one and many-to-many schemes deal with transportation between customers (Cordeau et al., 2008). Second, the setting of nodes in the PDP is associated with selectivity, depot supply/demand, and time window. Selectivity of nodes relaxes the requirement of visiting all vertices, depot supply/demand indicates whether the depot supplies or demands commodities, and time window limits the time for vehicles to visit nodes. Third, the considerations to vehicles include vehicle capacity and the number of available vehicles. Finally, regarding the properties of commodity, some PDP variants assume that there exists only one type (homogeneous) of commodities to be delivered while some consider multiple types (heterogeneous). The setting of transfer enables temporary stock of commodities (or passengers) in transshipment nodes. The fragment allows for partial delivery of commodities.

The one-to-many-to-one (1-M-1) scheme involves two types of commodities that originate from and terminate at the depot respectively. This scheme is widely used to deal with the issues in reverse logistics (Gonzalez-Torre et al., 2004; Mutha and

Table 1
Classification of PDP variants. (Sel: selectivity, Dep: depot supply/demand, TW: time window, Cap: capacity, Num: number, Ho: homogeneity, Fr: fragment, Tr: transfer).

Scheme	Node			Vehicle		Commodity			Variants
	Sel	Dep	TW	Cap	Num	Ho	Fr	Tr	
1-M-1		+			1				**TSPB** (Gendreau et al., 1996)
		+		+	1				**TSPPD** (Gendreau et al., 1999; Berbeglia and Hahn, 2009)
									SVRPPD (Gribkovskaia et al., 2007)
		+		+	*				**VRPB** (Toth and Vigo, 1997; Garcia-Najera, 2012)
									VRPPD (Gribkovskaia et al., 2001; Hoff et al., 2009)
									VRPSPD (Ai and Kachitvichyanukul, 2009; Çatay, 2010; Subramanian et al., 2010, 2011; Goksal et al., in press)
		+	+	+	*				**VRPBTW** (Duhamel et al., 1997)
									FDPPTW (Wang and Chen, in press)
	+	+		+	1				**SVRPDSP** (Gribkovskaia et al., 2008)
	+	+	+	+	*				**VRPDSPTW** (Gutiérrez-Jarpa et al., 2010)
1-1					1				**PDTSP** (Renaud et al., 2000, 2002)
									TSPPD (Dumitrescu et al., 2010)
									TSPPDF (Erdoğan et al., 2009; Cordeau et al., 2010a)
									TSPPDL (Cordeau et al., 2010b; Tu et al., 2010)
				+	1				***m*-PDTSP** (Hernández-Pérez and Salazar-González, 2009)
				+	*				**Ship Routing Problem** (Pang et al., 2011)
			+	+	1				**S-DARP** (Heilporn et al., 2011)
			+	+	*				**PDPTW** (Cheung et al., 2008; Ropke and Cordeau, 2009; Baldacci et al., 2011)
									VRPPD-G (Psaraftis, 2011)
			+		*			+	**PDPTW** (Shang and Cuff, 1996)
			+	+	*			+	**PDPT** (Cortés et al., 2010)
			+	+	*		+		**m-TSPTW** (Zhang et al., 2009, 2011)
M-M		+		+	1	+			***k*-Delivery TSP** (Chalasani and Motwani, 1999)
									CTSPPD (Anily and Bramel, 1999)
									1-PDTSP (Hernández-Pérez and Salazar-González, 2003, 2004a, 2004b; Hernández-Pérez et al., 2009; Zhao et al., 2009; Louveaux and Salazar-González, 2009)
	+	+		+	1	+			**1-TSP-SELPD** (Falcon et al., 2010)
		+		+	1			+	**SP** (Anily and Hassin, 1992; Bordenave et al., 2009; Anily et al., 2011)
									MSP (Bordenave et al., 2010)
									NCSP (Erdoğan et al., 2010)
	+			+	1	+			**SPDP**