Transportation Research Part E 85 (2016) 69–89

Contents lists available at ScienceDirect

Transportation Research Part E

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

Adaptive large neighborhood search heuristics for the vehicle routing problem with stochastic demands and weight-related cost

Zhixing Luo [a], Hu Qin [b,*], Dezhi Zhang [c], Andrew Lim [a,d]

[a] International Center of Management Science and Engineering, School of Management and Engineering, Nanjing University, Nanjing 210093, PR China
[b] School of Management, Huazhong University of Science and Technology, No. 1037, Luoyu Road, Wuhan, PR China
[c] School of Traffic & Transportation Engineering, Central South University, Changsha, Hunan 410075, China
[d] Department of Industrial & Systems Engineering, National University of Singapore 1, Engineering Drive 2, Singapore 117576, Singapore

ARTICLE INFO

Article history:
Received 13 March 2015
Received in revised form 4 October 2015
Accepted 8 November 2015
Available online 10 December 2015

Keywords:
Routing
Stochastic demands
Weight-related cost
A priori optimization
Adaptive large neighborhood search

ABSTRACT

The vehicle routing problem (VRP) with stochastic demands and weight-related cost is an extension of the VRP. Although some researchers have studied the VRP with either stochastic demands or weight-related cost, the literature on this problem is quite limited. We adopt the a priori optimization to tackle this problem and propose a dynamic programming to compute the expected cost of each route. We develop the adaptive large neighborhood search heuristics equipped with several approximate methods for the problem. To evaluate our heuristics, we generate 84 test instances. Computational results demonstrate the performance of our heuristics and can serve as benchmarks for future researchers.

1. Introduction

This study introduces a variant of the vehicle routing problem (VRP) in which the customer demands are random variables with known discrete probability distributions, the transportation cost per unit distance is a monotonically increasing function $c(w)$ of the vehicle weight w, and each customer can be served by exactly one vehicle. The customer demand is revealed only after this customer is visited by a vehicle. We call this problem the *VRP with stochastic demands and weight-related cost* (VRPSDW), which belongs to a type of rich VRP (Caceres-Cruz et al., 2014).

In many real life situations (Yang et al., 2000; Huang and Lin, 2010; Yan et al., 2013; Allahviranloo et al., 2014), customers have stochastic demands, which necessitates the investigation of the VRP with stochastic demands (VRPSD). The stochastic demand may lead to *route failures* when demand realization exceeds the residual capacity of the vehicle. Upon encountering a route failure, the vehicle has to take a *recourse action*, i.e., returns to the depot to unload all cargo and then continues to visit the remaining customers. This implies that a customer may be visited more than once and each visit fulfills a portion of demands. This feature can be found in the split delivery VRP (SDVRP) (Archetti and Speranza, 2012), but the SDVRP allows the customer to be served by more than one vehicle. Different from the classical VRP, the objective of the VRPSD is to minimize the total expected travel distance of all involved vehicles. In recent years, an increasing number of researchers have

* Corresponding author.
E-mail addresses: luozx.hkphd@gmail.com (Z. Luo), tigerqin1980@gmail.com (H. Qin), dzzhang@csu.edu.cn (D. Zhang), alim.china@gmail.com (A. Lim).

http://dx.doi.org/10.1016/j.tre.2015.11.004
1366-5545/

devoted to studying the VRPSD; for more details of this problem, we refer the reader to Rei et al. (2010), Erera et al. (2010), Gupta et al. (2012), Gounaris et al. (2013), Gauvin et al. (2014), and Goodson (2015).

The applications of the vehicle routing models with weight-related costs can be found in Chinese transportation system (Zhang et al., 2012). By the end of 2013, over 28 Chinese provinces have implemented the toll-by-weight scheme in which expressway tolls are levied according to the weight and travel distance of the vehicle. Before implementing the toll-by-weight scheme, tolls in Chinese expressways have been levied based on the tonnage or seating capacity and the travel distance of the vehicle. Under the old toll scheme, the vehicle was charged the same toll regardless of its weight, which violates the principle of equity where more loads should incur greater cost. In addition, this toll scheme motivated transportation companies to overload their vehicles to the greatest extent for economic benefits. The overloading brings about several obvious and serious issues, such as the damage of the expressways, and the increasing safety risk to drivers and other expressway users. Now under the toll-by-weight scheme, transportation companies have to load their vehicles at a reasonable level and pay the tolls in accordance with the vehicle weight.

The influence of the vehicle weight has also been studied in several VRP variants that consider the costs of fuel and greenhouse gas (GHG) emissions in their objective functions (Demir et al., 2014). Ubeda et al. (2011) provided a concrete example on how to reduce the environmental impact by optimizing the fleet routes in a Spanish supermarket chain. Undoubtedly, the fuel consumption is related to the vehicle weight; for example, for a vehicle, its fully loaded status might consume more than twice as much diesel fuel as its empty status. During the last decade, the hazardous impacts of GHG, which is directly related to the consumption of fossil fuel, have being receiving increasing concerns from the public (Lera-López et al., 2014). The transportation service providers have to undertake the cost of their GHG emissions in the context of new regulations. The cost of fuel consumed or GHG emitted per unit distance can be represented by a monotonically increasing function of the vehicle weight.

The focus of this study is to develop adaptive large neighborhood search (ALNS) heuristics (Ropke and Pisinger, 2006) to find high quality a priori optimization solutions for the VRPSDW. When executing the a priori routes, we propose a dynamic recourse strategy, which is more flexible and complicated than the existing recourse strategies in literature. In most metaheuristics for the VRPSD, the process of computing the expected cost of a given solution is computationally expensive. To alleviate the computational burden, similar to some previous articles (e.g., see Gendreau et al., 1996; Bianchi et al., 2006), we design several approximation schemes to quickly obtain the approximate expected cost of the VRPSDW route. Next, the methods of evaluating a removal or an insertion operation are derived from these approximation schemes. Finally, we embed the move evaluation methods into the framework of the ALNS heuristic to solve the problem. Since no benchmark instances exist in literature, we generate a set of test instances based on the real information from seven Chinese provinces.

The remainder of the paper is organized as follows. After providing an overview of the relevant existing literature on the VRPSDW in Section 2, we formally describe this problem as well as some of its properties in Section 3. In Section 4.1, we introduce three approximation schemes to compute the approximate expected cost of a route. In Section 4.2, we detail the ALNS heuristics, including the framework, the large neighborhood, the adaptive mechanism, the acceptance criteria, the procedure of generating initial solution, the move evaluation methods, and the removal and insertion heuristics. The computational results are reported in Section 5, followed by the conclusions with some closing remarks in Section 6.

2. Literature review

The VRPSD is one of the popular combinatorial optimization problems with stochastic parameters (Van Hentenryck and Bent, 2009). Since the only difference of the VRPSD and the classical VRP is the stochastic demand, Juan et al. (2011, 2013) tried to obtain the near optimal solution of the VRPSD by transforming a VRPSD instance to a set of VRP instances. The majority of literature papers adopted three main solution concepts for the VRPSD, which are *chance constrained programming* (CCP), *reoptimization* and *a priori optimization* (Psaraftis, 1995). The CCP model tries to find a set of routes that minimizes the total expected cost while guaranteeing that the probability of route failure is not greater than a threshold value (Stewart and Golden, 1983; Bastian and Rinnooy Kan, 1992). Stewart and Golden (1983) have shown that the CCP models can be transformed into an equivalent deterministic VRP model under some mild assumptions and therefore can be solved by the existing deterministic VRP algorithms.

Under the *reoptimization* concept, after fulfilling the demand of a customer, the vehicle makes decisions on which customer to visit next or whether a return trip is performed based on its residual capacity and the set of unserved customers (Secomandi and Margot, 2009). In other words, the output of the reoptimization approach is a policy that prescribes how the route should evolve, rather than a set of preplanned routes (Psaraftis, 1995). Dror et al. (1989) formulated the reoptimization type VRPSD as a Markov decision process (MDP) model. However, they neither discussed the structural properties of the model nor attempted to devise solution procedures. To solve the reoptimization type VRPSD, Secomandi (2000, 2001, 2003) expended significant efforts in proposing one-step rollout algorithms, which iteratively invoke the cyclic heuristic of Bertsimas et al. (1995). Novoa and Storer (2009) developed a two-step rollout algorithm that provides better solutions than the one-step version. Secomandi and Margot (2009) presented a finite-horizon MDP model that is more restrictive than the previous ones, and heuristically solved the model with the help of two partial reoptimization heuristics, namely, the partitioning heuristic and the sliding heuristic.