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Collaboration and transportation resource sharing in multiple centers vehicle routing optimization with delivery and pickup

Yong Wang[a,b,*], Jie Zhang[a], Kevin Assogba[c,*], Yong Liu[a,*], Maozeng Xu[a], Yinhai Wang[d,e]

[a] School of Economics and Management, Chongqing Jiaotong University, Chongqing 400074, China
[b] School of Management and Economics, University of Electronic Science and Technology, Chengdu 610054, China
[c] School of Civil and Construction Engineering, Oregon State University, Corvallis, OR 97331, USA
[d] Department of Civil and Environmental Engineering, University of Washington, Seattle, WA 98195-2700, USA
[e] Transportation Data Science Research Center, College of Transportation Engineering, Tongji University, Shanghai 201804, China

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ABSTRACT

The adoption of collaboration strategies among logistics facilities and the formation of one or multiple coalitions constitute a sustainable approach to vehicle routing network optimization. This paper introduces a collaborative multiple centers vehicle routing problem with simultaneous delivery and pickup (CMCVRPSDP) to minimize operating cost and the total number of vehicles in the network. Distribution and pickup centers are allowed to share vehicles and customers in order to increase the entire network's efficiency and maximize profit. To provide the coalition coordinators with good routing solutions, we propose a hybrid heuristic algorithm which properly combines k-means and Non-dominated Sorting Genetic Algorithm-II (NSGA-II). Based on clustering solutions, the proposed Hybrid NSGA-II (HNSGA-II) first generates a real coded population to bind our mathematical model constraints and to obtain a large number of feasible solutions which converge to optimality. Chromosomes are divided for genetic operations with partial mapped crossover and swap mutation algorithms, before their recombination to ensure the quality of our results. Comparisons with the traditional NSGA-II and the Multi-Objective Particle Swarm Optimization (MOPSO) algorithm indicate better performances of HNSGA-II in terms of objective function values. We also apply Cost Gap Allocation method (CGA) and the strictly monotonic path selection principle to examine profit allocation schemes. Numerical analyses on part of Chongqing city's logistics network show the superiority of HNSGA-II over MOPSO and NSGA-II on the practical case study, as well that of CGA over the Minimum Costs-Remaining Savings (MCRS), Shapley and Game Quadratic Programming (GQP) methods. In addition, the proposed profit allocation approach has supported the establishment of a grand coalition instead of two sub-coalitions. CMCVRPSDP optimization reduces long-haul transportation, improves the vehicle loading rate and facilitates sustainable development. Through the rational allocation of profits, the proposed solution methodology assures the stability and fairness among coalition members. The implementation is also important to design sustainable urban transportation networks.

1. Introduction

Modern supply chain managers have widely considered the reduction of operation cost, the improvement of service quality and the awareness of environmental impacts as decision making objectives. Among other ways to achieve these goals, vehicle routing optimization has received significant attention and is valued as an important component of supply chain optimization. Some of the related research have focused on the optimization of distribution networks where vehicles simultaneously perform delivery and pickup activities [2,36]. The use of the same vehicle to deliver and collect goods during the same trip significantly contributes to save cost and resource. Nevertheless, its implementation in real world environment needs improvement because simultaneous deliveries and pickups influence transportation related expenses but not other constituent of total operating cost such as the establishment, warehousing and maintenance cost. Consequently, some researchers have recently integrated collaboration among logistics facilities to minimize cost, reduce traffic congestion, increase carriers' profit and for policy control [4,29].

Cooperative game theory mainly focuses on horizontal and vertical

* Corresponding authors.
E-mail addresses: yongwx@cqjtu.edu.cn (Y. Wang), kevinassogba@gmail.com (K. Assogba), liuevery@gmail.com (Y. Liu), xmzzrxhy@cqjtu.edu.cn (M. Xu), yinhai@uw.edu (Y. Wang).

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synergies among participants [9,48]. Frisk and Gonnqvist [16] focused on forest products' transportation, encouraged collaboration between foresters and introduced a cost saving approach based on the forward and backward flows between suppliers and customers. Carriers in cooperative supply chain usually share customers and vehicles in order to optimize the use of their corresponding fleets and avoid empty truck transportation [5,12]. Therefore, the operating cost reduces and every facility makes significant benefits. Promoting collaboration between logistics facilities also aims at surviving in highly competitive environments and maximizing cost savings [26,28]. However, fairness in profit allocation and the reliability of the coordinator constitute critical issues to address for the stability of coalitions. Several approaches can separately be applied or combined to facilitate the rapid achievement of stability. Wang et al. [42] proposed the implementation of an integrated operational transportation approach consisting in combining horizontal and vertical synergies and negotiating vehicle fleets from external subcontractors in a vertical cooperation. Guajardo and Rönnqvist [19] assumed difficulties in managing grand coalitions and studied players partitioning problem in order to maintain core stability, strong equilibrium and the cardinality of each coalition.

Extensive studies were also done on Multiple Depots Vehicle Routing Problems (MDVRP) and their variants [20,38,43]. Due to difficulties engendered by the complexity of distribution networks, the search of good optimization solutions is considered as a Non-deterministic Polynomial Hard (NP Hard) problem. Therefore, the majority of research has generally designed heuristics and dynamic algorithms to increase solution quality. Kuo and Wang [25] proposed a variable neighborhood search algorithm based on stochastic initial solutions to solve MDVRP with loading cost. Nguyen et al. [32] proposed an improved tabu search algorithm with an adaptive neighborhood search strategy to assess time-dependent multi-zone multi-trip optimization solutions. Narasimha et al. [33] extended the ant colony optimization algorithm by including region partitioning to solve min–max MDVRP. Birim [6] introduced cross-docking and studied the vehicle routing problem with delivery and pickup vehicle starting and ending at cross-docks. Vehicle fleet heterogeneity was assumed, and a simulated annealing algorithm was proposed to search the best solution. Ting et al. [40] introduced the multi-vehicle selective pickup and delivery problem (MVSPDP) by relaxing vehicle constraints that require visiting every pickup node. Results suggested that solving MVSPDP yields less transportation cost than typical the pickup and delivery problem.

In order to improve service reliability, computation speed and reduce operating cost, several researchers have opted for the integration of clustering algorithm as an intermediate step in optimization and an important tool for modern logistics management [34]. Vicari and Alfó [41] used the joint clustering model of customers and products, and proposed an EM-type algorithm for ML parameter estimation. Kuo et al. [24] combined customer segmentation with heuristics to propose relevant marketing strategies. Calvet et al. [8] proposed a hybrid approach that combines statistical learning for customer demand estimation with metaheuristic algorithm, and applied their method to solve MDVRP. Defryn and Sörensen [15] proposed an improved two-level heuristic for clustered vehicle routing optimization. Assuming the number of clusters were predefined and equal to the number of vehicles, the problem mainly consisted in the design of routes in each cluster.

A comparative summary of existing research articles and the current study is presented in Table 1. Although scholars have already studied multi-depot vehicle routing problem with delivery and pickup, there are few studies which consider the formation of coalition between distribution centers (DCs) or pickup centers (PCs), and few MDVRP articles have focused on how to form more stable coalition as well as the allocation of benefit among participants. Collaboration benefits companies, but the formation process can be confronted to some challenges. Facilities may initially refuse to share their clients or resources. Thus, the coordinator should initiate persuasive negotiation and convince participants by highlighting the importance of a coalition as well as its advantages. It is important to highlight that the rationalization of profit allocation constitutes a core subject that coordinators need to carefully approach to maintain stability.

This paper studies the vehicle routing problem before and after collaboration along with profit allocation. The introduction of collaboration between different logistics facilities extends the vehicle routing problem with simultaneous delivery and pickup (VRPSDP) to the collaborative multiple centers VRPSDP (CMCVRPSDP). Subsequently, a Hybrid Non-dominated Sorting Genetic Algorithm-II (HNSGA-II) which incorporates customer clustering is utilized to compute operating cost and number of vehicles in the existing network, and to optimize the network through collaboration and transportation resource sharing. Upon routing optimization, we search good solutions to profit allocation by applying four different methods: Shapley value model, MCRS, GQP and CGA. Finally, a practical case study of Chongqing city, China is used to evaluate the performance of our approach in real word environment.

Solving the CMCVRPSDP is a practical subject in logistics and transportation domain. Optimization solutions foster the collaboration between distribution and pickup centers and provide more systematic decisions for a better management of city logistics network. Another benefit is the reduction of transportation cost for both DCs and PCs by encouraging semitrailer truck and vehicle sharing. Besides, CMCVRPSDP optimization facilitates the reduction of traffic congestion and pollution in urban areas, and provides more profits to companies and governments.

Combining observations in Table 1, this article contributes in the following aspects: (1) We introduce a collaboration mechanism between distribution and pickup centers integrating customers, semitrailer trucks and vehicles sharing; (2) A bi-objective model to simultaneously minimize operating cost and number of vehicles is designed to evaluate the impact of collaboration on the original logistics network; (3) A hybrid non-dominated sorting genetic algorithm-II with the capability of local and global search is proposed for routing optimization, and the cost gap allocation method is used to find the best profit distribution plan for each coalition; (4) We conducted empirical analyses on an important transportation hub in China, Chongqing city, to demonstrate the use of the proposed CMCVRPSDP optimization methodology in real world.

The rest of this article is organized as follows. Section 2 illustrates the CMCVRPSDP and introduces a bi-objective model to minimize operating cost and number of vehicles. In Section 3, we design hybrid heuristic algorithm for routing optimization and introduce the cost gap allocation method for profit allocation. In Section 4, a practical study on the CMCVRPSDP in Chongqing city, China, is conducted to thoroughly analyze the importance of collaboration. The conclusion summarizes the results and proposes future research directions.

2. Problem statements and model formulation

2.1. Definition

CMCVRPSDP optimization is a tactical supply chain decision which can improve vehicle loading rate, reduce cost and generate benefit. In our study, we consider a network containing multiple DCs, PCs and customers. Fig. 1 shows the difference in the routing network before and after MCVRP optimization. The DCs and PCs are independent before collaboration, whereas they can cooperate and achieve a more organized transportation network after optimization.

As shown in Fig. 1(a), before collaboration, three DCs and two PCs are used to serve customers among which some are relatively closer to other competitors. In real life, the establishment of distribution or pickup centers is a gradual process, and as customers have already reached a significant level of confidence and loyalty towards a logistics