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An exact algorithm for the multi-trip vehicle routing and scheduling problem of pickup and delivery of customers to the airport

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ABSTRACT

Door-to-Door service of Pickup and Delivery of Customers to the Airport (D2PDCA) is a new service provided by certain Airline Ticket Sales Agencies (ATSAs) in China. This new service provides an attractive alternative way by picking up customer at this/her specified position and at any time he/she preferred and delivering to the airport more conveniently than airport shuttle and thus earn high customer service quality. Compared with the single-trip mode, the multi-trip mode of D2PDCA (MTM-D2PDCA) service can reduce travel distances, the number of vehicles required and the operating cost. To obtain the exact solution of the MTM-D2PDCA problem, we propose a novel, exact algorithm based on the trip-chain-oriented set-partitioning (TCO-SP) model, where a trip-chain represents multiple trips made by a specific vehicle. In the exact algorithm, we propose an improved label-correcting method to remove infeasible trip-chains quickly and thus speed the search process. Based on the feasible trip-chains, the MTM-D2PDCA problem is formulated as the novel TCO-SP model, which can be solved exactly by the optimization software CPLEX. In addition, we present several mathematical insights into the relationship between the number of trip-chains and the number of local optimal trips that are applicable in both theory and practice. Extensive experiments are conducted to illustrate the application of the model and demonstrate the cost savings of the MTM-D2PDCA mode over the single-trip mode and provide managerial insights into successfully operating a MTM-D2PDCA service.
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1. Introduction

With the high speed of economic development, the service industry has received considerable attention, particularly in China. The ratio of the production value of the service industry to the GDP of China has grown by more than 15%. In the service industry, customer satisfaction and operating costs are the key factors in earning market share and, consequently, enhancing competitiveness in a global market. Therefore, operating a transportation service with both low operating costs and high service quality has become an important issue for most decision makers, especially those who have to make daily decisions.

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Airline Ticket Sales Agencies (ATSAs) are common service companies in the Chinese aviation services industry. Their major services include ticket sales, flight line design, and free delivery of tickets to customers. To gain market share, various new services and value-added programs have been introduced by some ATSAs. For example, a service for "door-to-door picking up and delivering customers to the airport" (D2PDCA) is provided by Zhongshan Flight Ticket Sales Service Company Inc. in Shenyang. With the D2PDCA service, customers who bought airline tickets can be picked up at a preferred time and location and delivered to the airport by a specified time at no extra cost. This new service can transport customers to the airport more conveniently and at a lower cost and thus enhances customer satisfaction. This service can increase revenue and market-share for ATSAs in the long term, even though it may create additional operating costs in transportation and vehicle rentals.

According to a survey of a large ATSA in the city of Shenyang, Zhongshan Flight Ticket Sales Service Company Inc., the average number of customers reserving tickets per day can reach 200 and approximately 50% intend to use the D2PDCA service. Although 1/5 of the total profits per day will be spent on D2PDCA by Zhongshan Inc., over the past five years, the company has been very successful in attracting customers by implementing this service. However, the search for methods to diminish operating costs and enhance service quality has never stopped.

All of the previous research on D2PDCA has focused on single trips. The single-trip mode of D2PDCA can be described as follows: each vehicle starts from the depot, picks up and delivers the customers to the airport, and then returns to the depot. In the single-trip mode, each vehicle will complete only one trip during the schedule. Tang et al. (2008) established a multi-objective model for minimizing costs and maximizing service quality and solved this problem using a two-stage heuristic algorithm based on the savings algorithm of Clarke and Wright (1964). Dong et al. (2008) researched a model for minimizing costs using permutation-based cluster priority heuristics. Dong et al. (2011) proposed an exact algorithm for the single-trip mode D2PDCA based on a set-partitioning model. The algorithm has two phases: constructing the trips and solving the set-partitioning model based on the trips.

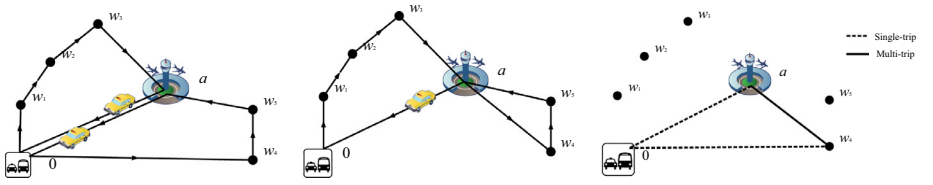
However, the multi-trip mode for D2PDCA (MTM-D2PDCA) is more appropriate in certain practical situations. The MTM-D2PDCA can be described as that in which each vehicle starts from the depot and picks up and delivers the customers to the airport and then, starting from the airport, shuttles other customers to the airport continuously. Unlike the single-trip mode, in the multi-trip mode each vehicle may make many trips.

Consider a D2PDCA example with 5 customer nodes to illustrate the difference between the single-trip mode and the multi-trip mode, as shown in Fig. 1. Fig. 1(a) depicts the single-trip mode, where two vehicles are used, Fig. 1(b) displays the multi-trip mode, where only one vehicle is used, and Fig. 1(c) presents the difference in the distance traveled between the two modes.

Fig. 1 shows that the multi-trip mode can reduce the number of vehicles used and the driving distance. Therefore, the MTM-D2PDCA problem is more significant in theory and in practice. In the MTM-D2PDCA problem, to minimize the cost the ATSA must decide how to arrange the vehicles to pick up and deliver the customers to the airport in multiple trips. Concurrently, there are many realistic constraints that must be taken into consideration such as at the required arrival times at the airport, the vehicle trip durations, the capacity of the vehicles, and the ride times of the customers.

The MTM-D2PDCA problem is a special case of the Vehicle Routing Problem with Time Windows and Multiple Trips (VRPTWM), which is a variant of the Vehicle Routing Problem with Multiple Trips (VRPM) addressed by Fleischmann (1990). The variant problems of VRP have been researched widely (Zhong and Cole, 2005; Liu et al., 2009; Yu and Yang, 2011; Gulczynski et al., 2010; Li et al., 2009). VRPM is also known as a variant of the Vehicle Routing Problem (VRP). The VRPM and its variant the VRPTWM have received considerable attention. The commonly-used objectives include minimizing the total operating cost, the routing cost, the number of the vehicles used, and the maximum overtime. Regarding the constraints, Taillard et al. (1996), Petch and Salhi (2003), and Olivera and Viera (2007) all considered the duration of the routes assigned to the same vehicle as a constraint. In addition, time windows were considered in the research of Azi et al. (2007), Battarra et al. (2009), and Azi et al. (2010). It is noteworthy that all this research focused on the distribution of goods rather than the transportation of people.

An early survey of heuristic solutions for the VRPM and the VRPTWM was conducted by Fleischmann (1990), where he combined the classical savings algorithm for the VRP with a bin packing heuristic to aggregate routes. A three-phase heuristic was proposed by Petch and Salhi (2003) to solve a variant of the problem to minimize the maximum overtime. Their population-based approach first generates routes with a savings-based heuristic. These routes are then combined to form complete solutions that are improved with a local search heuristic. Olivera and Viera (2007) presented an adaptive memory-based heuristic, where the memory consisted of multiple route solutions. Battarra et al. (2009) proposed an



(a) Single-trip mode (b) Multi-trip mode (c) Distance difference

Fig. 1. An example of single-trip mode and multi-trip mode.

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