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An unpaired pickup and delivery problem with time dependent assignment costs: Application in air cargo transportation

Farshid Azadian[a,*], Alper Murat[b], Ratna Babu Chinnam[b]

[a] College of Business, Embry-Riddle Aeronautical University, 600 S. Clyde Morris Blvd., Daytona Beach, FL 32114, USA
[b] Department of Industrial and Systems Engineering, Wayne State University, 4815 Fourth Street, Detroit, MI, 48202, USA

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ABSTRACT

This study considers a freight forwarder's operational implementation of alternative access airport policy in a multi-airport region for cargo transportation. Given a set of heterogeneous air cargo customers, the forwarder's problem is to simultaneously select air cargo flight itineraries and schedule the pickup and delivery of customer loads to the airport(s). This problem is formulated as a novel pickup and delivery problem, where the delivery cost is both destination and time dependent. A mixed-integer linear model in presented and an efficient solution method based on decomposition is developed. The performance of the solution algorithm is evaluated by computational experimental study.

1. Introduction

Over the past two decades, air mode of transportation for carrying goods around the globe has become a vital part of many companies' logistics. The demand for air cargo demonstrated steady growth and is expected to maintain the trend despite the economic crisis of the past few years. Annual forecast reports by Airbus (2015) and Boeing (2015) predict 4.4 to 4.7 percent annual growth for global air cargo tonnage over the next 20 years, respectively. Similar to a growing demand for air transportation, although not at the same rate, the aviation industry has also expanded and air transportation has become more accessible to shippers with more options and at more locations. In the domestic US market, construction of new airports, capacity expansion of existing airports, conversion of some military airports to civilian airports, increase in the aviation network connectivity, availability of more flight itineraries, and improved road accessibility of airports cause the service zones of airports to expand and, often, overlap. This has resulted in the creation of Multi-Airport Regions (MARs) where several airports are accessible in a region and can substitute and supplement each other in meeting the region's demand for air transportation (Loo, 2008). Hall (2002) proposed the Alternative Access Airport Policy (AAAP) and argued that for air cargo transportation considering multiple airports (and subsequently flight itinerary options) in a MAR can be beneficial to reduce truck mileage, decrease sorting and handling costs, improve delivery service level, and avoid congestion on both road and air networks. He has used the case of Southern California to point out the potentials for AAAP in addressing the complexities of responding to increasing demand in that region.

While Hall (2002) outlined and discussed the advantages of the AAAP, to the best of our knowledge, there is no study on the modeling and implementation of AAAP. In this paper, we consider a freight forwarder's operational implementation of AAAP in air cargo transportation. The freight forwarders, who are intermediaries between shippers and carriers, are responsible for more than 90% of air cargo shipments (Hellermann, 2006). Shippers are often only concerned with the safe arrival of their cargo to the destination at a reasonable price and increasingly move toward leaving all the routing and booking decisions to freight forwarders. Accordingly, freight forwarders are responsible for finding the best flight itinerary options and booking capacity with air carriers to get the cargo to its destination before delivery due date.

A flight itinerary option refers to a set of one or multiple connecting flights that carry cargo from its origin to its final destination. Various flight itinerary options may share some flight legs. For instance, a flight leg from the origin airport to an airline hub is shared among all the flight itinerary options that fly through that hub. The process of routing cargo on a scheduled air network to establish the best flight itinerary options and calculate their costs and destination arrival times is a complex problem. Azadian, Murat, and Chinnam (2012) studied this problem and provided an algorithm for air cargo routing and dynamic rerouting. We rely on their research for identifying the flight itinerary options and calculating their costs. In the case of a MAR and under the AAAP, there

* Corresponding author.
E-mail addresses: azadianf@erau.edu, f_azadian@yahoo.com (F. Azadian), amurat@wayne.edu (A. Murat), ratna.chinnam@wayne.edu (R.B. Chinnam).

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may be a large number of feasible flight itineraries that need to be considered for each customer's load (see Appendix C for an illustrative example).

In addition to flight booking, forwarders are also responsible for the pickup and delivery of customers' loads, which is often performed by a fleet of hired trucks. When customers' loads are less-than-truck-load, which is a common case for air cargo, consolidating loads of multiple customers in a single truck trip provides an opportunity to reduce logistics costs. In fact, the profitability of a forwarder relies directly on its overall cost efficiency, which depends on the flight itinerary decisions as well as pickup and delivery operations. The combination of these decisions constitutes a very complex operational management problem. Our objective, in this paper, is to introduce and model this practical problem and provide a novel solution methodology for it from the perspective of a freight forwarder.

The forwarders problem constitutes of two sets of decisions. One decision component in this problem is the flight itinerary assignment to different customers' loads that are geographically dispersed in the MAR. These decisions are driven by the availability of flight itinerary options, cargo acceptance cut-off times, destination arrival times, flight itinerary costs, and tardiness penalties. The other decision component is the multi-vehicle routing to pick up customer loads and deliver them to the airports prior to the cut-off times for cargo acceptance of the assigned flight itineraries. These routing decisions are affected by the locations (depot, customers, and airports), starting times of the selected flight itineraries, and the vehicle fleet size. The structure of the forwarders problems generalizes the Pickup and Delivery Problems (PDP) in several aspects and demand the introduction of a new type of the PDPs. Our contributions in this research are threefold. First, we introduce and model the operational implementation of the AAAP for freight forwarders in a MAR, which generalizes several known pickup and delivery problems in terms of model structure and objective function. Second, we propose a novel and efficient decomposition based solution methodology, which can also be used for the new class of pickup and delivery problems. Finally, we present the results of an experimental study to evaluate the performance of the proposed algorithm.

The rest of this paper is organized as follows. We briefly review the relevant literature in Section 2 and point out the gap in the existing literature. In Section 3, we present a detailed account of the problem modeling and formulation. In Section 4, we demonstrate the shortcomings of traditional methods in solving the problem and develop a solution methodology that is able to solve the problem efficiently. In Section 5, we evaluate the performance of our solution method and report on the results of the computational study with experimental problem instances. Section 6 concludes the paper with a discussion and future research directions.

2. Related Literature

The freight forwarder's operational implementation of the AAAP is closely related to the pickup and delivery problem. *Pickup and delivery problems* have been extensively studied in the past decades; for a comprehensive survey see Berbeglia, Cordeau, and Laporte (2010), Berbeglia, Cordeau, Gribkovskaia, and Laporte (2007), Laporte (1992, 2009), Parragh, Doerner, and Hartl (2008a, b), and Toth and Vigo (2001). Generally, the PDP involves routing a fleet of vehicles to satisfy a set of transportation requests between the given origins and destinations. In the PDP, all the origin pickups must precede the destination deliveries and be performed by the same vehicle. Moreover, each route must start and terminate at the same location (i.e., depot). The PDP usually considers capacitated vehicles and the goal is to minimize a criterion related to a travel measure. The travel measure can be as simple as the total travel distance for urban commercial vehicles (Figliozzi, 2007) or more complex as the total excess riding time over the direct ride time in passenger transportation (Diana & Dessouky, 2004). The PDP can be classified into two categories: transportation between customers and the depot, and transportation between the pickup and delivery locations (Parragh et al., 2008a). The proposed problem in this paper falls into the latter category, as the depot (the starting point of trucks) does not generate or accept any load. This category can be further classified into paired and unpaired pickup and delivery locations.

In the paired PDP, also known as the *One-to-One* PDP (1-1-PDP), the load picked up from a customer location can only be delivered to one of the delivery locations associated with the given customer. Some customers, however, may share the same delivery location. In the *stacker-crane problem* (SCP), unit loads of non-identical commodities have to be transported from the origin to the destination using a unit capacity vehicle (Frederickson, 1978). In the *Vehicle Routing Problem with Pickup and Delivery* (VRPPD), the unit capacity requirement of SCP is relaxed and replaced with a set of constraints based on the load properties (e.g., weight, volume, or unit count). A special case of the VRPPD is the *VRPPD with Time Windows* (VRPPDTW) where visiting a pickup or delivery location is only allowed during a predefined time window. While the VRPPD generally concerns goods transportation, the *dial-a-ride problem* (DARP) addresses passenger transportation and therefore includes additional side constraints (e.g., maximum ride time, time windows, or service quality). Moreover, the objective function optimizes measures such as customers (in)convenience; see Cordeau and Laporte (2007), Kirchler and Calvo (2013), and Paquette, Cordeau, Laporte, and Pascoal (2013) for a survey of recent modeling and solution algorithms for DARP.

In comparison, the unpaired PDPs, also known as *Many-to-Many* PDP problems (M-M-PDP), consider the case where any commodity can be picked up and delivered to delivery locations that accept the commodity. The M-M-PDP was initiated with Anily and Hassin (1992) that introduced the *swapping problem* (SP) for moving n-commodity objects between customers with a single unit capacity vehicle. In the SP, each customer supplies one type of commodity and demands a different type. In addition to the n-commodity case of the SP, there are several other single commodity problems that are studied under the M-M-PDP where picked up loads are homogenous. Hernández-Pérez and Salazar-González (2004a, b, 2007) introduced and studied the *one-commodity pickup and delivery traveling salesman problem* (1-PDTSP). The 1-PDTSP is a more general case of the *Q-delivery traveling salesman problem* (Q-DTSP) by Chalasani and Motwani (1999) and the *capacitated traveling salesman problem with pickup and deliveries* (CTSPPD) by Anily and Bramel (1999). In the 1-PDTSP, a single vehicle, starting from a depot, transports goods from pickup nodes to delivery nodes without exceeding the vehicle capacity; the objective is to minimize the total traveling cost. Q-DTSP and CTSPPD are special cases of 1-PDTSP where the pickup and delivery quantities are all one unit and the vehicle capacity is restricted (i.e., Q units). Hernández-Pérez and Salazar-González (2009) later extend their 1-PDTSP to the *Multi-Commodity One-to-One Pickup and Delivery Traveling Salesman Problem* (m-PDTSP); however, with this extension, the problem is not an M-M-PDP anymore. The multi-commodity variation was studied by Hernández-Pérez and Salazar-González (2014). In the multi-commodity variation, a given picked up commodity can be used to satisfy any demand of that commodity disregarding the origin.

The problem of the forwarder's operational implementation of the AAAP is essentially a PDP as it consists of transporting loads from customer sites (pickup locations) to the airports (delivery locations) in a MAR. The depot is both the origin and final destination of the vehicles, although, it is neither pickup nor a delivery point. Despite the similarities, the proposed problem has