European Journal of Operational Research 244 (2015) 955–965

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Innovative Applications of O.R.

The Airline Container Loading Problem with pickup and delivery

Virginie Lurkin*, Michaël Schyns

HEC Management School, University of Liege, QuantOM 4000, Liège, Belgium

ARTICLE INFO

Article history:
Received 14 December 2013
Accepted 11 February 2015
Available online 20 February 2015

Keywords:
OR in airlines
Assignment problem
Fuel consumption
Weight and balance
Sequencing problem

ABSTRACT

This paper considers the loading optimization problem for a set of containers and pallets transported into a cargo aircraft that serves multiple airports. Because of pickup and delivery operations that occur at intermediate airports, this problem is simultaneously a Weight & Balance Problem and a Sequencing Problem. Our objective is to minimize fuel and handling operation costs. This problem is shown to be NP-hard. We resort to a mixed integer linear program. Based on real-world data from a professional partner (TNT Airways), we perform numerical experiments using a standard B&C library. This approach yields better solutions than traditional manual planning, which results in substantial cost savings.

1. Introduction

In the *Airline Container Loading Problem with Pickup and Delivery* (ACLPPD), a set of containers and pallets, known as *Unit Load Devices (ULD)*, must be loaded into a compartmentalized cargo aircraft. We consider that pickup and delivery operations occur at different airports during any given trip. The loading task is illustrated in Fig. 1. We propose an exact solution approach that relies on a mixed integer linear program to find the optimal ULD assignment.

Air cargo represents 10 percent of the world trade volume, but its value is in excess of $6.4 trillion per annum, which is approximately 35 percent of the world trade value (IATA, 2013a). Thus, air cargo transportation plays a highly significant economic role. Optimizing loading assignment on board is critical to airlines for several reasons. First, correct loading conditions safety. Inappropriate loading can cause significant damage, and place the aircraft, the freight or even the crew at risk. Therefore, this paper models a wide set of constraints for operators to consider daily. The proposed model applies to all aircraft and loads, and complies with international standards. Considering the same constraints as Limbourg, Schyns, and Laporte (2012), we adapt such constraints to the case of a sequence of routes, called *legs*, while considering the additional case of hazardous products and oversized ULDs. Second, optimal loading has a positive impact on aerodynamics, thus resulting in less fuel consumption, i.e., reduced cost and environmental impact. This issue is crucial for airlines, affected by rising oil prices and increased pressure to reduce carbon dioxide emissions. This paper analyzes fuel and handling operations in order to minimize costs. The management of these first two requirements is done through a proper distribution of the ULD weights within the aircraft. This part is a Weight & Balance Problem. The third reason optimal loading is important for airlines is that managing operations on the ground is challenging, especially when the trip includes several legs with P&D operations. Reducing the number of handling operations reduces time, which in turn reduces labor costs per flight. Such reduction also allows shorter turnaround time, i.e., the time that elapses from the moment the plane arrives to the moment it leaves again, thus reducing airport fees. Time saved could be used for other valuable operations. Optimizing loading plans is also crucial and constitutes another reason to consider this problem. Indeed, loadmasters must build plans within an extremely short time, and doing so manually requires significant time. On the other hand, with an interactive computerized efficient tool, loadmasters would be able to consider different alternatives and select the best solution with respect to their experience and the real conditions faced on the ground.

In this context, the problem no longer consists merely, as in Limbourg et al. (2012), in positioning ULDs to reach a proper equilibrium, but also in defining the unloading and loading operation sequence at airports. Because there is only one path between any ULD and the exit door, this path must be free to unload ULDs. The task is to minimize, at each airport, the number of ULDs in transit to be unloaded in order to have access to the ULDs reaching their delivery point. The same question arises when pickup occurs. The problem is even more complex when several doors can be used, as occurs occasionally. The cost of these handling operations is the second element of our proposed objective function. It is important to notice that we face two conflicting objectives: optimizing board assignments for fuel and for ground operations. Our contribution is to propose an exact

* Corresponding author.
E-mail addresses: vlurkin@ulg.ac.be (V. Lurkin), M.Schyns@ulg.ac.be (M. Schyns).

http://dx.doi.org/10.1016/j.ejor.2015.02.027
0377-2217/

Fig. 1. ULD loaded through main deck side cargo door (left), through nose door (middle), and through lower deck side cargo door (right).

approach to solve simultaneously both the Weight & Balance Problem over a multi-leg trip, and the sequencing problems associated to pickups and deliveries. We resort to a mixed integer linear program where the objective is to minimize both costs.

Currently, this extremely complex problem (NP-hard) is still essentially solved manually based on best practices. Because load planners have extremely short time windows to choose assignments, they focus mainly on finding a feasible and reasonable solution. As a rule, they do not incorporate P&D operations in the planning process. A common method for managing several legs is, indeed, to plan each leg independently. Accordingly, almost the entire cargo can be unloaded at intermediate airports, and the ULDs that have not reached final destinations are reloaded subsequently, which is the worst possible scenario for ground operations. We show, based on of our first results from real data provided by industrial partners, that our approach allows significant savings.

The remainder of this paper is organized as follows. Section 2 outlines the problem and the assumptions involved. Related literature and contributions are presented in Section 3. Section 4 describes the problem in more detail, and provides the proposed model's mathematical formulation. Section 5 provides information on the theoretical complexity of the problem, whereas Section 6 illustrates the performance of the approach through numerical results. Finally, some conclusions are drawn.

2. Problem summary and assumptions

ACLPPD can be informally summarized as:

min	Fuel and loading operations costs on the entire trip (global optimization)
s.t.	Pickup and delivery sequences are feasible
	Customer demand is satisfied (each ULD is loaded)
	Each ULD fits in an aircraft position
	A position accepts only one ULD
	Some positions overlap and cannot be used simultaneously
	Longitudinal stability is within certified limits (ZFW, TOW, LW)
	Lateral stability is within certified limits
	Weight per position is below certified limit
	Combined weight load limits are set
	Cumulative weight load limits are set
	Regulations for hazardous goods are fulfilled
	Oversized ULDs are managed

The decision variables are the location of each ULD within the aircraft. The constraints are described in detail in Section 4.3. We make the following main assumptions. A cargo aircraft has to deliver goods to several airports. The flight plan is presumably known in advance, which means that the airports and the order in which they will be visited are known. We also knowall the containers and pallets (ULDs) to be delivered. For each ULD, we know its size, shape, weight, and respective origin and destination. We follow international standards for ULD description. Full details on the coding standards can be found in the *International Air Transport Association (IATA) ULD Regulations (ULDR)* (IATA, 2013b). A cargo aircraft generally contains multiple decks with multiple position configurations for each deck. A position is simply a particular aircraft space that accommodates exactly one ULD. The location of each position and that of all ULDs that fit into such position are also known. The location of the different doors is also given. A cargo aircraft has generally one side cargo door on the main deck and one for each of the three compartments of the lower deck. In addition, a nose door is sometimes available for the main deck. An example of cargo aircraft structure is illustrated in Fig. 2. The focus of this research is on cargo transportation. The central ideas remain the same and extensions of our approach can be considered; however, passenger transportation and the transportation of goods in the lower deck of passenger aircraft are beyond the scope of this paper.

3. Related literature and contributions

This problem is an Assignment Problem (AP) that is referred in the literature as belonging to the family of Weight & Balance Problems. Over the past years, more attention has been paid to the problem that precedes ACLPPD by considering how to optimize freight loading within ULDs (Chan, Bhagwat, Kumar, Tiwari, & Lam, 2006; Li, Tao, & Wang, 2009; Paquay, Schyns, & Limbourg, 2014; Tang, 2011; Tang & Chang, 2010; Wu, 2010; Yan, Shih, & Shiao, 2008) independently of aircrafts. The scientific literature on aircraft cargo load planning is not extensive, but contains a number of papers.

Prior publications differ in many ways. First, the literature can be subdivided according to two approaches: bin packing and assignment. In the Bin Packing Problem (BPP) approach (for examples, see Amiouny, Bartholdi, Vande Vate, & Zhang, 1992; Guèret, Jussien, Lhomme, Pavageau, & Prins, 2003; Heidelberg, Parnell, & Ames, 1998; Nance, Roesener, & Moore, 2011), the authors attempted to fill the aircraft continuously by excluding empty spaces between the items, whereas in the AP approach (for examples, see Larsen & Mikkelsen, 1980; Limbourg et al., 2012; Mongeau & Bès, 2003; Vancroonenburg, Verstichel, Tavernier, & Vanden Berghe, 2014), the authors attempted to allocate ULDs into predefined standardized positions, similar to our approach. Second, several papers treated the problem with exact approaches (for examples, see Guèret et al., 2003; Limbourg et al., 2012; Mongeau & Bès, 2003; Vancroonenburg et al., 2014), whereas others developed heuristics (for examples, see Amiouny et al., 1992; Heidelberg et al., 1998; Larsen & Mikkelsen, 1980; Nance et al., 2011). Third, some papers attempted to determine how to select the ULDs or items to be loaded in an aircraft or a fleet of aircraft (for examples see Fok & Chun, 2004; Mongeau & Bès, 2003; Vancroonenburg et al., 2014), whereas others assumed that all ULDs must be loaded in the aircraft, similar to us (for examples, see Amiouny et al., 1992; Larsen & Mikkelsen, 1980; Limbourg et al., 2012). Fourth, some papers